AN ANALYSIS OF THE

SURFACE HYDROLOGY IN THE

GALENA WATERSHED: 1940 - 1987

by

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This study analyzes the impact soil conservation methods have ~~had~~ on runoff in a topographically steep, intensely cultivated watershed in Southwestern Wisconsin. The time period studied is unique as little soil conservation measures were used in the early 1940s compared to a dramatic increase in the late 1970s and 1980s. The influence increased soil conservation practices have ~~had~~ on the surface hydrology appears to have significantly reduced surface runoff while increasing baseflow.

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ABSTRACT

This study attempts to evaluate the influence of soil conservation practices on the surface hydrology in the Galena watershed from 1940 through 1987. Poor soil conservation practices within the Galena watershed from the mid-1800s until the mid-1900s increased surface runoff while decreasing baseflow. The poor soil conservation practices influenced soil erosion, flood magnitudes, channel morphology, and sedimentation processes.

The influence of poor soil conservation practices within the Galena watershed reached a maximum during the early 1900s. Efforts begun by the Soil Erosion Service in the mid-1930s began to reduce surface runoff by educating farmers in proper soil conservation methods. Aerial photography analysis indicates a steady increase in strip cropping and contour farming since 1937. The increased use of soil conservation practices within the Galena watershed have decreased surface runoff more than 20% and increased the baseflow.

The influence of soil conservation was evaluated by controlling climatic variables through an analysis of similar storm events. Statistical analyses indicates similarity among the storm events, reducing the climatic

influence. Hydrographs corresponding to the selected storms were analyzed and an estimation of surface runoff and baseflow calculated for each storms throughout the study period. Overall results indicate a general decreasing trend in surface runoff with a corresponding increasing trend in baseflow during the study period.

CHAPTER 1: INTRODUCTION

The primary objective of this study is to compare storm runoff hydrology as it changed from the early 1940s through the late 1980s. A specific attempt is made to evaluate the influence that soil conservation practices have had on the surface runoff hydrology of the intensively cultivated, topographically steep Galena watershed upstream of the U.S. Geological Survey (U.S.G.S.) stream gage (#05415000) at Buncombe, Wisconsin from 1940 through 1987. Specific goals of this study are to quantitatively determine the influence that cultivation and conservation practices have had on the following:

1. the surface runoff fraction of total runoff;
2. the base flow fraction of total runoff;

and,

3. the lag time between precipitation events and peak river discharge.

The study area is a medium sized, intensely cultivated, unglaciated watershed located in southwestern Wisconsin (see Figure 1). The agricultural land use in this watershed changed significantly from the early 1940s to the late 1980s due to farmers

GALENA WATERSHED

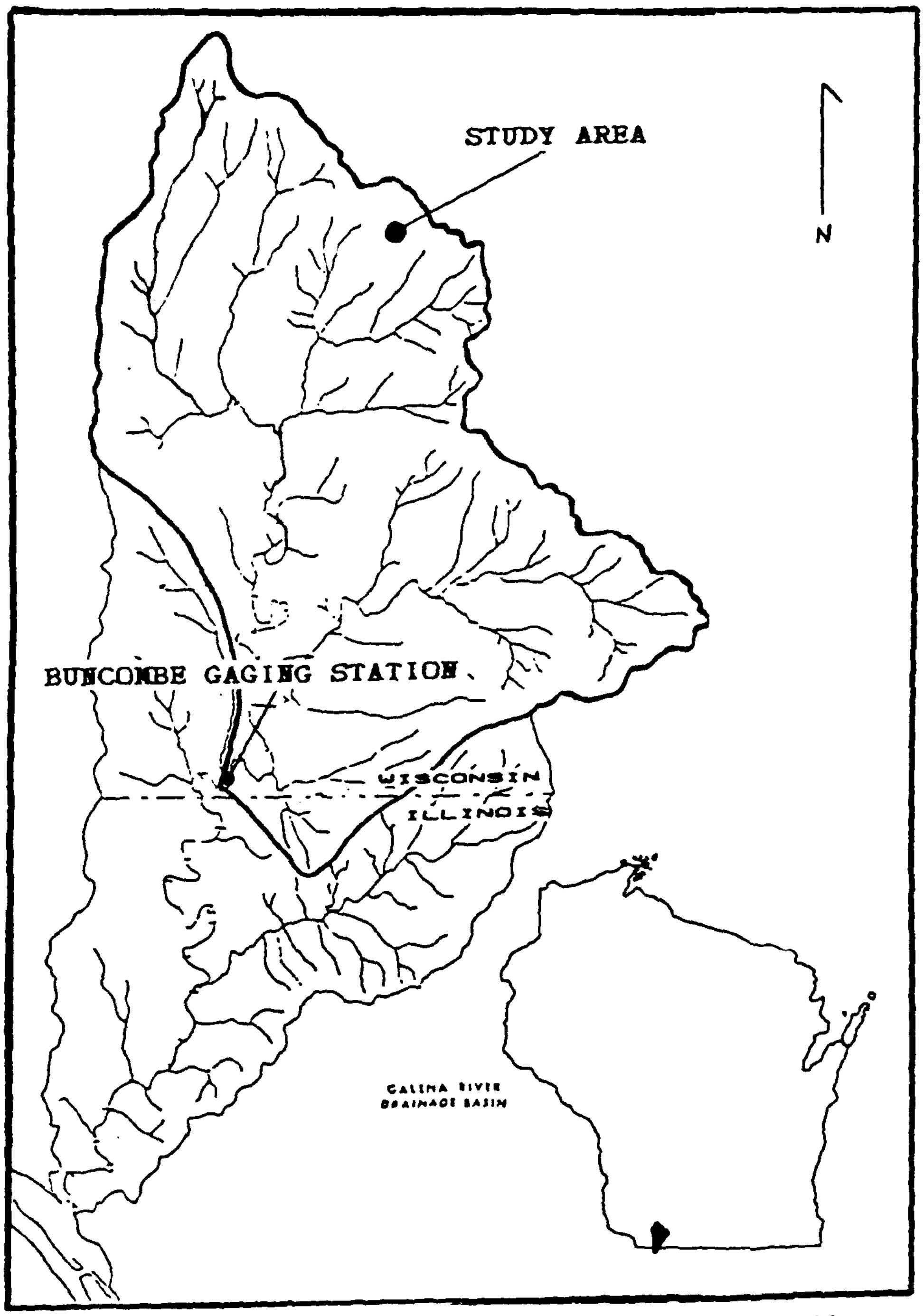

Figure 1. The study area is that portion of the watershed upstream of the Buncombe gaging station. A small portion lies within Illinois.

adopting soil conservation practices.

Migration into the Midwest U.S. during the 19th and early 20th centuries may be the most flagrant example of land abuse by poor cultivation practices (Butzer, 1974). Reckless cultivation practices emphasized cultivating all available slopes, plowing perpendicular to slope contours, and stressing monocultures with practically no intercropping. In approximately 150 years the agricultural soil resources within the Midwest were reduced by perhaps 50% (Butzer, 1974). During the 1930s in the Midwest land abuse began to decline through educational efforts by the U.S. Soil Erosion Service and implementation of agricultural conservation practices.

The first intensive white settlement of southwestern Wisconsin began in the early 19th century with the discovery of rich lead and zinc deposits. However, within a decade or two it was the agriculture potential of the area that was responsible for continued settlement (Trewartha, 1940; Blanchard, 1924). Mining was a dominant activity until the mid-1840s due to its profitability, the uncertain agricultural productivity of the land, threats of Indian attacks until the close of the Black Hawk War in 1832, and federal restrictions preventing ownership and use of "mineral lands" for agricultural purposes (Blanchard, 1924). Federal policies changed in 1846 and agricultural activity intensified until the early 1900s. Since the late 1890s agricultural activity in this region has remained intense although the nature of land use has changed (Trimble and Lund, 1982; Blanchard, 1924).

Many farmers from western Europe were accustomed to gentle, persistent rainstorms and were not prepared for the high intensity rainstorms of the Midwest. Unknowing of the consequences, farmers cultivated sloping hill tops and steep valley side slopes. Such cultivation worked well in western Europe but was not well suited for the intense rainstorms encountered in the Midwest and the easily erodible loess-derived soils of the region. As time progressed and farming practices remained unchanged, surface runoff increased and soil erosion accelerated.

The stock market crash and the Dust Bowl drought of the early 1930s had a profound influence on the Midwest as well as the entire nation. These two events created an awareness of land resource and management policies. Some environmentalists recognize the period from the early 1930s until World War II as the Golden Era of environmental conservation because of the many programs and policies then initiated towards improving the environment (Petulla, 1977). Due to severe soil erosion in southwestern Wisconsin caused by farming practices, the U.S. Soil Erosion Service (later the U.S. Soil Conservation Service) and the University of Wisconsin established the first conservation demonstration area in 1933 located in the Coon Creek basin, approximately 125 kilometers northwest of the Galena River watershed (Wisconsin Blue Book, 1989). Goals of this conservation demonstration area were to educate farmers in soil conservation practices and to establish demonstration sites in communities to disseminate these practices (Johansen, 1969).

The soil conservation practices taught at Coon Creek disseminated slowly to the surrounding areas as only 233 farmers utilized soil conservation practices in 1939 within a 120 kilometer radius of the Coon Creek project (Johansen, 1969). Aerial photographs of the Galena watershed in 1937 indicate no cultivated land under the common soil conservation practices promoted by the Coon Creek demonstration project. The number of Wisconsin farmers practicing soil conservation within a 120 km radius of Coon Creek increased to 6402 by 1967 (Johansen, 1969). Similarly, aerial photographs taken in 1985 indicate a substantial fraction of cultivated land within the Galena watershed under soil conservation practices. Increased utilization of soil conservation practices have influenced surface hydrology and appear to have significantly reduced surface runoff in the Galena watershed during the study period.

This study derives its primary data from aerial photographs and climatic and discharge records. Aerial photographs were taken at sporadic intervals by the U.S. Department of Agriculture and U.S.G.S. from 1937 to 1985. Climatic data from four weather stations surrounding the Galena watershed provide the necessary precipitation data. The U.S.G.S. gaging station located on the Galena River near the Wisconsin - Illinois border at Buncombe provided the necessary discharge data. All records for this study date from 1940.

Agricultural land use changed significantly from the 1940s through the 1980s. This study attempts to compare the storm runoff from the 1940s to the 1980s within the intensely cultivated Galena watershed, focusing on hydrologic responses to increased levels of adoption of soil conservation practices.

CHAPTER 2: BACKGROUND

INTRODUCTION

Changes in land use disrupt surface hydrology by influencing the runoff processes within a watershed. Two principle components of runoff are baseflow and surface runoff. Baseflow consists of groundwater runoff and delayed subsurface runoff (Chow, 1964). The term 'surface runoff' best describes the combination of Horton overland flow, subsurface quick flow, and saturation overland flow (Mockus, 1972). Horton overland flow occurs when rainfall intensity exceeds soil infiltration capacity (Dunne and Leopold, 1978). Hydrographs illustrate both baseflow and surface runoff within a watershed. Most authors agree that specific factors influencing the runoff process can be classified as either climatic or physiographic influences (Chow, 1964; Wisler and Brater, 1963; Dunne and Leopold, 1978). Climatic and/or physiographic changes within a watershed often result in changes in the baseflow and surface runoff components of a hydrograph. This study examines storm runoff hydrographs of the Galena River at Buncombe, Wisconsin (drainage area 323 km^2) to evaluate the influence of changing agricultural land use on runoff hydrology since 1940.

RUNOFF COMPONENTS AND FACTORS

The baseflow component of a hydrograph fluctuates conservatively in response to precipitation events in comparison to more dramatic fluctuations of the surface runoff component. Singh (1972) identified three major factors that influence baseflow magnitude:

1. hydraulic characteristics of surficial soils;
2. groundwater aquifer characteristics;

and,

3. evapotranspiration demands.

Surficial soil characteristics determine the infiltration rate and the influence of antecedent precipitation which in turn determine the storage capacity and available water for aquifers. Groundwater aquifer characteristics affect baseflow by influencing the rate that groundwater moves into stream channels. Permeable aquifers will transport groundwater more rapidly into stream channels than less permeable aquifers. Evapotranspiration demands dictate the available water for baseflow. Baseflow usually declines in summer due to increased evapotranspiration.

Surface runoff is responsive to many aspects of watershed physiographic and climatic factors (Dunne, 1983). Rainfall intensity, storm duration, antecedent soil moisture, soil cover, and infiltration capacity influence Horton overland flow. Surface runoff occurs when rainfall exceeds storage and infiltration capacities. Horton overland flow occurs frequently in arid and semi-arid areas where vegetation is sparse and rainfalls are commonly intense.

Initial soil moisture, topography, and the geometry of the subsurface flow region influence the volume and rate of subsurface flow. Watersheds characterized by abundant subsurface flow tend to produce hydrographs with low peaks and relatively flat rising and recession limbs. Subsurface flow is dominant in areas with permeable soils and dense vegetation.

Saturation overland flow consists of return flow and direct precipitation onto saturated surfaces (Dunne and Leopold, 1978). Large rainstorms, wet antecedent soil conditions, long hillslopes with gentle gradients, and shallow soils with an infiltration capacity that exceeds the rainfall intensity but is too low to convey all the rainfall as subsurface flow influence saturation overland flow. Areas with watertables that easily and rapidly rise to the ground surface during rainfall produce saturation overland flow. Saturation overland flow dominates watersheds that are sparsely vegetated with thin soils, have high water tables, and have long gentle concave hillsides.

Climatic factors may be grouped into three specific categories including precipitation, interception, and evapotranspiration (Chow, 1964). Precipitation factors include the form of precipitation, storm type, intensity, duration, areal distribution, frequency of occurrence, direction of storm movement, antecedent precipitation, and soil moisture. Interception factors focus on vegetation composition, age, density of stands, and seasonal development. Evapotranspiration factors include temperature, wind, atmospheric pressure, the nature and shape of evaporative surfaces, solar radiation, soil moisture, humidity, and types of vegetation.

Physiographic factors include physical factors and land use (Chow, 1964). Physical factors include watershed size, shape, slope, orientation, elevation, stream density, and related factors emphasizing infiltration processes and soils. Land use is a separate consideration in this study due to its dominant hydrologic role during the study period of the 1940s - 1980s.

RUNOFF PROCESS

Most climatic and physiographic factors remain relatively constant during this study period and have no direct influence on the aspects analyzed. Land use changes during this study period and has a significant influence on the runoff process.

The runoff process is continuous over time and does not have a beginning or ending point. Hoyt (1942) describes the runoff process by delineating five phases:

1. the rainless period just prior to the beginning of rainfall and after an extended dry period;
2. the initial period of rain which involves:
    a. precipitation in the channel.
    b. interception by vegetation.
    c. infiltration into the soil.
    d. temporary retention in small depressions;
3. the continuation of rainfall at variable rates;
4. the continuation of rainfall until all natural storage is satisfied;

and,

5. the period between termination of rainfall and the first phase.

The five phases provide a framework for analyzing the influence that soil conservation practices have had on surface runoff and baseflow.

The first phase determines soil moisture just prior to rainfall and influences baseflow. A high soil moisture content before rainfall produces increased surface runoff. The influence of initial soil moisture on surface runoff ceases when the soil becomes saturated during rainfall (Hawley et al., 1983). Baseflow depends on available moisture within the watershed and groundwater. Prolonged periods between rainstorms decrease available soil moisture within the watershed and deplete groundwater reserves that in turn decrease magnitudes of baseflow prior to rainfall. Soil conservation practices increase available moisture within a watershed by retaining rainfall within the watershed and by releasing water into drainage channels at a reduced rate.

Hoyt's second, third, and fourth phases represent gradual accumulation of precipitation and the filling of storage reservoirs. Strip cropping and contour farming influence both baseflow and surface runoff by decreasing exposed soil and effective slope length, increasing storage capacity, and improving soil infiltration capacity. Overall, soil conservation practices reduce surface runoff during this phase.

During Hoyt's fifth phase baseflow continues while surface runoff ends. A temporary new higher baseflow may occur if infiltration has been sufficient to reach the zone of saturation. Soil conservation practices increase the infiltration rate enhancing the possibility of increased baseflow. The fifth phase may recycle into the first phase.

Artificial drainage by drain tiles influences the runoff process by reducing groundwater levels and increasing the rate of subsurface flow into drainage channels. Agricultural watersheds utilizing drain tiles and other forms of artificial drainage tend to have gentle slopes with minimal relief; under those conditions saturated soils hinder cultivation. The relief and stream density of the Galena watershed is sufficiently great that little artificial drainage is practiced. Records pertaining to artificial drainage within the Galena watershed do not exist. Conversations with U.S.G.S. personnel and aerial photograph analysis during this study period indicate no artificial drainage within the watershed.

PREVIOUS RESEARCH IN THE STUDY AREA

There is an extensive body of literature describing the physical geography of southwestern Wisconsin during the first half of the 20th century. Blanchard (1924), Martin (1932), Trewartha (1940), and Knox (1972; 1977; and 1987) provide the interested reader detailed discussions about the vegetation and surface hydrology of the Driftless area since the early 1800s. The intent of this study is not to conduct an extensive literature review of previous studies, but to focus on a quantitative runoff analysis. The following is a brief discussion of key literature highlighting aspects most relevant to this study.

Blanchard (1924) and Trewartha (1940) described the vegetation encountered by the first settlers in southwestern Wisconsin. The topography and climate of the Driftless area favored forests consisting mainly of oak that "fringed the streams and occupied the valleys" with upland prairies consisting of "thick, tough, sod" (Blanchard, 1924, pp. 68 - 69). The dense, thick vegetation prior to the introduction of agriculture provided a very stable land cover with good infiltration minimizing surface runoff.

A dominant crop of the southern Driftless area from the earliest settlers through present times is corn. The influx of corn and other cultivation radically changed the surface hydrology by reducing the natural vegetation, decreasing infiltration, and greatly increasing the portion of total runoff that was surface runoff.

Many previous studies concerning changing surface hydrology in the Midwest focus on historical sedimentation to illustrate changes in land use since the early 1800s. Knox (1972; 1977; 1987) cites the destruction of natural vegetation during cultivation of uplands and valley sides in southwestern Wisconsin since 1830 as apparent causes for increased magnitudes and frequency of peak discharges, enlarged channel cross sections in headwater and tributary reaches, and considerable vertical accretion of sediment on floodplains in downstream valleys.

Conversion of natural land to agricultural land use since the 1830s caused a three-to-five-fold increase in the magnitudes of floods in the Platte watershed of southwestern Wisconsin, a watershed adjacent to the Galena watershed, indicating a significant increase in surface runoff (Knox, 1977). Estimates of runoff changes between the 1830s and the 1960s in the Bear Branch tributary of the Platte River in southwestern

Wisconsin indicate a tripling of peak flows from surface runoff of moderate magnitude storms. Prior to the 1950s, increases in peak flows probably exceeded the three-fold magnitude of the 1960s due to the lack of agricultural conservation practices such as strip cropping and contour plowing (Knox, 1977). Knox (1977) identified a sequence of hydrologic responses from the conversion of natural land cover to agricultural land use and cultivation practices: 1830s - 1860s, low magnitude disturbance; 1870s - 1940s, maximum disturbance; 1950s - 1970s, moderate disturbance. The period from 1950s - 1970s extends into the 1980s. Hydrologic disturbance appears to subside with time in this later period due to the implementation of agricultural conservation practices.

Trimble and Lund (1982) compared agricultural practices of the 1930s and the 1970s to evaluate the influence of agricultural conservation practices on soil erosion in the Coon Creek Basin, Wisconsin. The area surrounding Coon Creek in 1934 consisted of rectangular fields on moderate to steep slopes, poor crop rotations, removal of crop residues, insufficient manuring, nutrient depletion, lack of cover crops, and very active erosion. The same area in the mid 1970s portrayed contour plowing, strip cropping, long crop rotations, incorporation of crop residues into the soil, manuring, and cover crops. The improvement in agricultural practices within the Coon Creek Basin has increased soil infiltration capacities and converted what would have been a significant portion of surface runoff into subsurface flow, thereby reducing soil erosion. Trimble and Lund discount a climatic influence believing that climatic cycles superimpose perturbations on overall trends caused by agricultural conservation practices.

Sartz (1976) monitored runoff response to the influence of different land uses at the Coulee Experimental Forest near LaCrosse, Wisconsin. Sartz found that runoff from cultivated land was ten times greater than a lightly grazed pasture and approximately 20 times greater than runoff from a forested pasture. Agricultural conservation practices were not evaluated.

Sartz (1974) studied the influence that non-cultivation agricultural practices have on runoff by comparing grazed watersheds in southwestern Wisconsin. Runoff magnitudes decreased several times within only two years after grazing was discontinued in one watershed, illustrating the wide variety of agricultural conservation practices available to decrease runoff.

C.M. Adamson (1974) studied two similar small watersheds in Australia focusing on the influence that soil conservation practices have on surface runoff. Both watersheds consisted of undisturbed natural prairie at the beginning of the study. Adamson maintained one watershed at its original condition while contour plowing and fertilization were applied to the other watershed. Results indicate a reduction in surface runoff of 74% in the treated watershed during the 21 year study. The reduction was attributed to increased infiltration and water storage capacity from contour plowing.

SUMMARY

The runoff process consists of many interrelated factors influenced by land use. Soil conservation practices influence runoff from agricultural land by reducing surface runoff and increasing baseflow. Poor documentation of historical events complicate an accurate description of surface runoff response to changing land use.

CHAPTER 3: DESCRIPTION OF THE GALENA WATERSHED

The Galena watershed is within the Driftless area of southwestern Wisconsin and northwestern Illinois. The study area is upstream of the Buncombe, Wisconsin U.S. Geological Survey gaging station and lies primarily in Lafayette County, Wisconsin and a small area within Jo Daviess County, Illinois (Figure 1). The U.S.G.S. operates a continuous recording discharge gage located at the SW 1/4, Section 33, T1N, R1E, 4th P.M., in Lafayette County, Wisconsin. Operation of the continuous recording discharge gage began in December, 1939. The medium-size Galena watershed is 323 square kilometers in area. Terrain within the watershed is highly dissected with local relief ranging from 5 - 15 meters per square kilometer (m/km^2) in the northern portion to 70 - 100 m/km^2 the steep southern valleys. Urbanization within the watershed is virtually non-existent with only a few small towns and numerous clusters of houses. Initial land use in the watershed was mining until the 1830's when agriculture became the predominant land use (Knox, 1987). The Galena watershed was chosen for study because of the availability of good historical records, aerial photographs, and because significant change in agricultural land use has occurred within the last fifty years.

The surficial bedrock of this area is Ordovician age and consists mainly of Galena dolomite with local exposures of Maquoketa shale (Agnew, 1963; Klemic and West, 1964; Mullens, 1964). The drainage pattern is dendritic and rectangular showing strong geologic influence through joint controlled valleys and lineated channel patterns. The shape of this watershed is elongated with the primary axis oriented slightly northwest to southeast. The orientation decreases the effectiveness of storm movement to magnify floods because most storms track from the south and west to the north and east (Bryson, 1966).

There are three soil associations within the Galena watershed associated primarily with loess deposited during the late Wisconsin (Watson, 1966, Knox, 1987). The Tama-Ashdale Association represents dark-colored, deep soils of the limestone uplands found mostly on the numerous broad ridge tops and adjoining slopes. Tama soils are approximately 125 centimeters thick while the Ashdale soils average 75 centimeters. Both Tama and Ashdale soils belong to the Mollisol soil order. Tama soils have an infiltration rate between 2.0 - 6.4 centimeters per hour (cm/hr) throughout the soil. The

Ashdale soils have an infiltration rate of 2.0 - 6.4 cm/hr from the land surface to 30 centimeters depth, 0.5 - 2.0 cm/hr from 30 - 100 centimeters depth and 0.13 - 0.5 cm/hr from 100 to approximately 125 centimeters depth (until the limestone parent material). The Tama-Ashdale association covers approximately 40% of the watershed.

The Fayette-Palsgrove association represents light-colored, deep soils also found on the limestone uplands. The association also represents approximately 40% of the watershed. Small piles of gravelly and stony waste material from lead and zinc mines ranging in size from 2 - 20 acres are found on the the Fayette-Palsgrove Association. Both Fayette and Palsgrove soils are 75 - 125 centimeters thick and belong to the Alfisol soil order. The Fayette soils have an infiltration rate of 2.0 - 6.4 cm/hr throughout the soil profile. The Palsgrove soils have the same infiltration rate as the Ashdale soils.

The Dubuque-Sogn Association represents light-colored moderately deep and dark colored shallow soils. Dubuque soils are 38 - 75 centimeters thick while the Sogn soils are the thinnest soils in the watershed, averaging 30 centimeters or less. Dubuque soils belong to the Alfisol soil order and have an infiltration rate of 2.0 - 6.4 cm/hr from the surface to 30 centimeters depth, 0.5 - 2.0 cm/hr from 30 - 75 centimeters depth, and 0.13 - 0.5 cm/hr from 75 centimeters depth to the limestone parent material. Sogn soils are the least fertile agricultural soils and they are found mostly on steep side slopes bordering stream valleys. They are very droughty, lack space for root development, and they are stony in many places. Sogn soils belong to the Entisol soil order and they have an infiltration rate of 2.0 - 6.4 cm/hr throughout their profiles. The Dubuque-Sogn Association covers approximately 20% of the watershed.

CHAPTER 4: METHODS

INTRODUCTION

This study utilizes three data sets: precipitation, stream runoff, and land use. Precipitation data consist of records from four weather stations surrounding the Galena watershed. Hydrographs of the Galena River provide necessary information to estimate surface runoff and baseflow data. Analyses of aerial photographs provide land use data. All data sets span the study period with minimal missing data. Statistical analyses were conducted to evaluate linkages between precipitation, runoff, and land use data sets.

PRECIPITATION

Precipitation occurring at weather stations located at Cuba City, Darlington, and Platteville, Wisconsin, and Galena, Illinois (Figure 2) was areally weighted by the Thiessen Polygon method (Dunne and Leopold, 1978) to estimate rainfall occurring within the watershed. The Cuba City station is the most important using the Thiessen method and is the only hourly recording station of the four. This study only considered rainfall occurring from April through October to avoid snowmelt and cold weather influences. To ensure the occurrence of stream

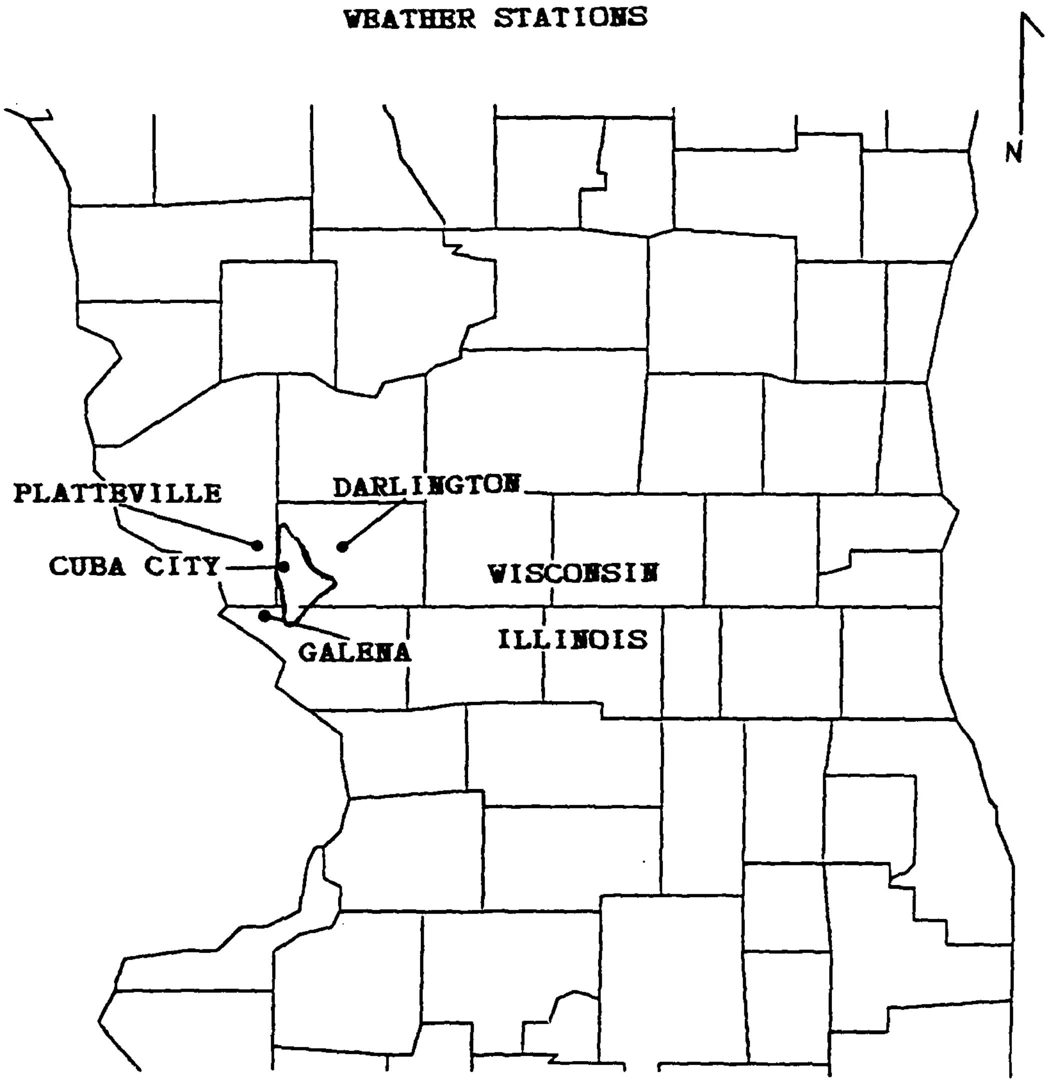

Figure 2. The spatial location of the four weather stations used in this study to determine the precipitation and temperature data.

runoff following precipitation, a decision was made to include in the analyses only those events for which at least 2.50 centimeters of precipitation occurred within 24 hours. A total of 145 storms equalling 2.50 cm have occurred within the study period 1940-1987. After adjusting to ensure homogeneity of the climate data base (further discussion in Chapter Five), 83 storms were selected for analyses. The selected storms were subdivided into three time periods based on the changing percentage of soil conservation practices obtained from land use analysis. The three resulting time periods are: 1940 - 1950, initial implementation of soil conservation practices; 1952 - 1968, moderate increase in soil conservation practices observed; and 1969 - 1987, representing a maximum level for application of soil conservation practices. Statistical analyses showed that storm intensities were similar between the three time periods.

SURFACE RUNOFF/BASEFLOW

The estimated percentages of surface runoff and baseflow for each storm result from quantifying components of corresponding storm hydrographs. Hydrographs of the Galena River taken at Buncombe, Wisconsin, for the selected storms were obtained from the U.S.G.S. Water Resources Division. Surface runoff duration for each storm resulted from a visual inspection of each hydrograph, denoting the interception of the rising limb, the peak stage position on the hydrograph, and the inception of the asymtotic position of the hydrograph. The surface runoff volume is estimated by measurement of the hydrograph area above a straight line connecting the inception points on the rising limb and the asymtotic recession limb. Base flow is the area of the hydrograph below that line. This method is not exact, but it is consistent throughout this analysis and therefore it is reasonably objective.

Each data base describing surface runoff and baseflow consists of a series of (X,Y) coordinates. The X axis represents time in hours and the Y axis represents discharge. A volume representing surface runoff and baseflow for each storm results from processing storm data bases through a Fortran program (Appendix 1).

LAND USE

This study uses aerial photographs to analyze changing land use during the study period. Aerial photographs taken at irregular intervals by the Agriculture Stabilization and Conservation Service

(A.S.C.S.) and the U.S.G.S. began in 1937. Photographs used in this study are from 1937, 1951, 1955, 1962, 1968, 1976, and 1985.

Percentages of land areas in various classifications were estimated by observing land uses along twelve east/west transects arranged from north to south within the Galena watershed (Figure 3). Distance between transects is approximately two kilometers to ensure an accurate account of land use in small order tributaries and headwaters. Transect locations were determined using permanent land marks such as road junctions and bridges. An opsometer was used to measure the four classifications of land use. Land use percentages resulted from the total length of the transects.

Photograph clarity restricts land use classification in this study to cultivated, non-cultivated, and forest. Analyses of the cultivated land determined the percentage of land associated with soil conservation practices, primarily strip cropping and contour farming.

STATISTICAL ANALYSIS

A comparison of rainfall intensities between the three time periods was conducted by using analysis of

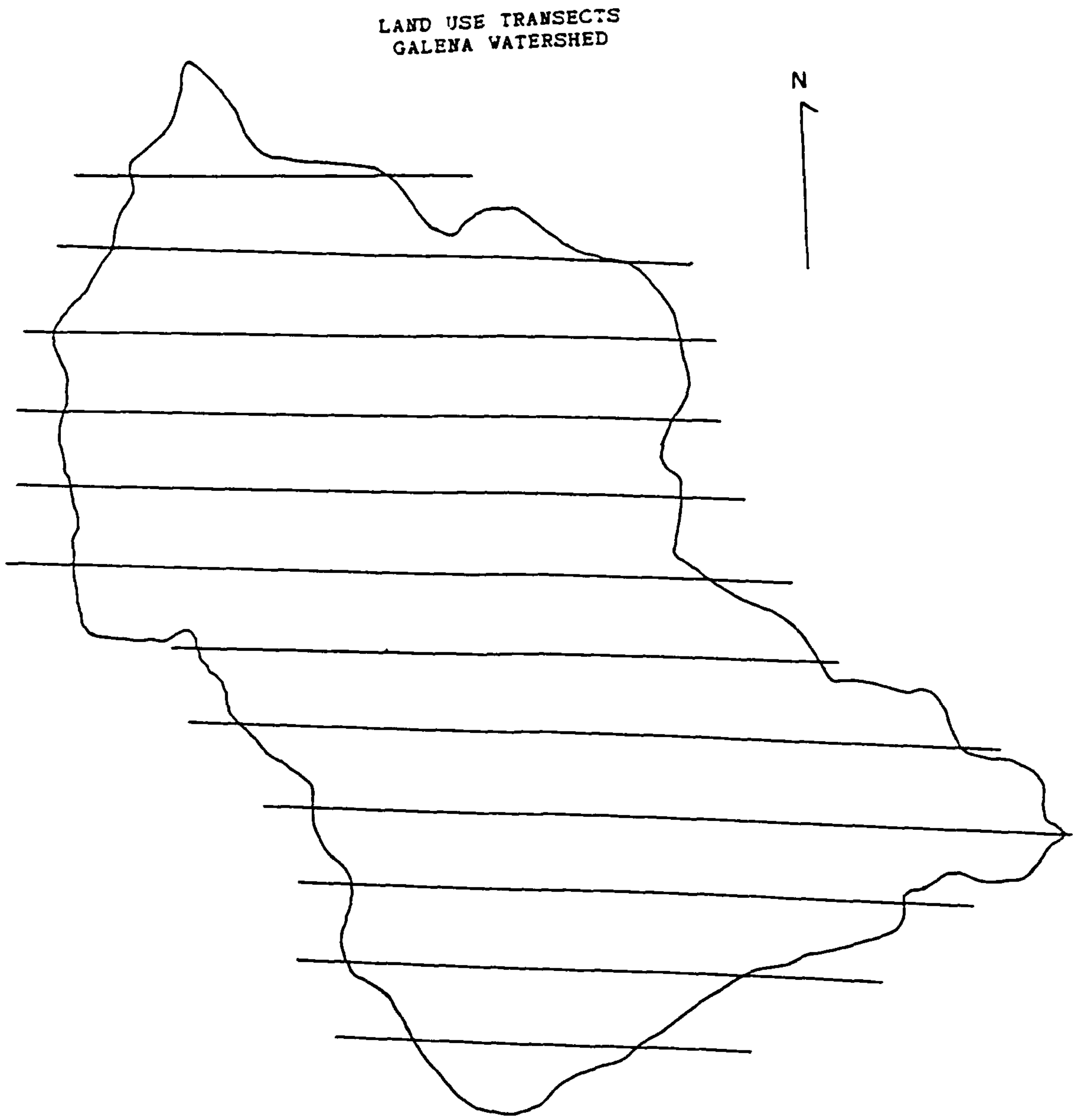

Figure 3. The spatial location of the twelve transects used to evaluate land use.

variance and other descriptive statistics. These analyses showed storm intensities between the three periods were not significantly different for the adjusted data.

Multiple regression analyses were applied to determine relationships and/or contributions of eight hydrologic variables that influence stream runoff.

CHAPTER 5: DATA ANALYSIS

INTRODUCTION

The objectives of this chapter are:

1. to explain the criteria used in selecting analyzed storms;
2. to analyze land use within the Galena watershed during the study period;
3. to analyze storm and runoff characteristics that could influence the percentage of surface runoff occurring during this study period;

and,

4. to compare storm and runoff characteristics between three periods of soil conservation intensity.

This chapter analyzes and compares characteristics of runoff events determined from hydrographs and storms from 1940 through 1987 to evaluate hydrologic response to increased utilization of soil conservation practices. Aerial photograph analysis defined three periods of varying degrees of soil conservation activity within the Galena watershed during the study period. Aerial photographs were used to classify land use within the Galena watershed during this study period into percent cultivated, non-cultivated, and forested. Further analysis determined the percentage of cultivated land utilizing soil conservation practices. Multiple regression analysis was then used to evaluate relationships between storm characteristics and runoff hydrographs for the study period.

STORM SELECTION

Storm rainfalls were selected from the records of four weather stations within or surrounding the Galena watershed. The stations are located at Meeker's Grove/Cuba City, Darlington, and Platteville, Wisconsin, and Galena, Illinois (Figure 2). The only hourly recording station among the four is the Meeker's Grove/Cuba City station located on the the western edge of the watershed. That record was used to estimate storm durations of the other three stations. The bias introduced by estimating storm durations for the other three stations is thought to be insignificant because the Meeker's Grove/Cuba City station is strongly dominant (87%/74% from the Thiessen Polygon method) in the allocation of rainfall on the watershed. Station histories from 1940 to 1988 indicate that all stations moved slightly on various occasions, but only one significant move occurred when the station located at

Meeker's Grove moved approximately 6.5 kilometers southwest to Cuba City in June 1951. It is not possible to calibrate the effects of the moves for any of the stations due to the lack of overlap in monitoring at the stations. The records of the four weather stations are very good with minimal missing data. Values for the occasional missing data were estimated using regression equations related to data from the other stations (Dunne and Leopold, 1978).

Because available weather stations are few in number and unevenly distributed in relation to the Galena study watershed, the Thiessen Polygon method (Dunne and Leopold, 1978) was applied to determine the relative watershed allocations of rainfall from the four stations. Thiessen polygon allocations show the respective influences of the precipitation events at the four stations on watershed runoff from 1940 to June 1951 are: Meeker's Grove - 87%, Darlington - 4%, Platteville - 4%, and Galena - 5%, and from June 1951 to 1988: Cuba City - 74%, Darlington - 10%, Platteville - 14%, and Galena - 2%. The Thiessen Polygon allocations were analyzed by correlating the rainfall of the four stations to the gage heights recorded at the Buncombe, WI, discharge station. This analysis linked a physical property, the discharge gage height, to the spatial distribution of the four stations. The resulting correlations supported the Thiessen allocations.

Assessment and comparison of the influence of changing land use on the relative fractions of surface versus baseflow runoff for the three time periods required selecting storms that were as similar as possible in amount and duration of precipitation. The expected two-year probability rainfall for the study watershed ranges from approximately 2.5 cm in 30 minutes to approximately 7.5 cm in 24 hours (Dunne and Leopold, 1978, pp. 58 - 63). Based on predicted intensities, the need to analyze storms that occur frequently, and to ensure a large sample size of storms that have sufficient intensity to produce significant surface runoff, a minimum storm intensity of 2.5 centimeters occurring within 24 hours was defined as a minimum threshold for inclusion. Only storms occurring from April through October were considered to avoid the influence of snowmelt and frozen ground. The threshold definition resulted in identification of 145 storms from 1940 to 1987.

The Thiessen method was applied with the other three stations on the initial sample of 145 storms. Analysis of variance was then conducted on the initial 145 storm sample precipitations and durations among the three time periods (Table 1). All analyses indicated similarity among time period precipitations magnitudes. However, a significant difference (0.03 probability level) occurred between the 1940s storm duration (mean of 19.12 hours) and the other two time period storm durations (means of 14.00 and 13.90 hours). The influence of the slightly longer storm duration for the 1940s is believed to be minimal. Overall, statistical analyses strongly indicate that climatic influences are similar throughout the study period and should not influence runoff analyses. However, to ensure homogeneity of the climatic influences the initial sample of 145 storms was adjusted resulting in a final sample set of 83 storms.

The initial sample of 145 storms were plotted on an X/Y coordinate system with the X axis representing duration and the Y axis representing the amount of precipitation (Figure 4). Extreme outliers unique to only one of the three groups were eliminated to promote similarity among the groups. Also eliminated were storms occurring within five days of a previous storm because they created a circumstance whereby the antecedent precipitation might greatly bias surface runoff (Mockus, 1972, and phone conservation with John Milligan, Soil Conservation Service, Madison, WI, June

TABLE 1 STATISTICS ON INITIAL 145 STORM SAMPLE

	MEAN	STANDARD DEVIATION	95% C.I. FOR PERIOD	F - RATIO FOR THREE PERIODS	PROBABILITY
STORM PRECIPITATION (IN CM):				0.81	0.45
TIME PERIOD 1 1940 - 1951	4.76	1.51	3.90 - 5.20		
TIME PERIOD 2 1952 - 1968	5.20	1.81	4.90 - 5.90		
TIME PERIOD 3 1969 - 1987	5.18	2.11	4.80 - 5.90		
STORM DURATION (IN HOURS):				3.70	0.03
TIME PERIOD 1 1940 - 1951	19.12	11.64	17.1 - 21.4		
TIME PERIOD 2 1952 - 1968	14.01	7.81	13.2 - 17.3		
TIME PERIOD 3 1969 - 1987	13.91	11.48	13.1 - 17.3		

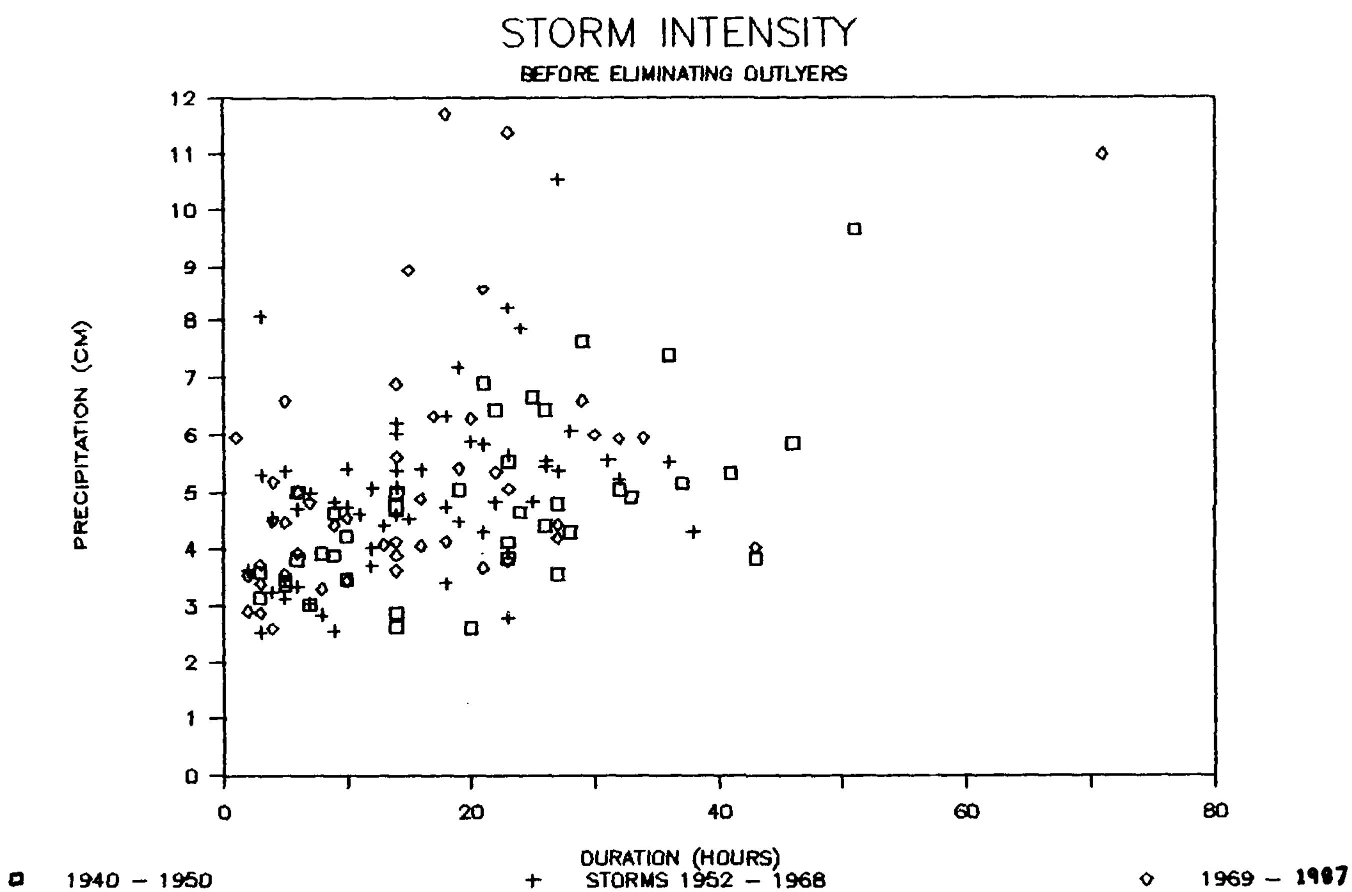

Figure 4. A plot of storm intensities for the initial 145 storms before eliminating outliers and storms not meeting antecedent precipitation criteria.

1989). The resulting 83 storms for the three time periods include 27 storms occurring from 1940 through 1950, 29 storms occurring from 1952 through 1968, and 27 storms occurring from 1969 through 1987 (Figure 5). Analysis of variance, with a research hypothesis that $u_1=u_2=u_3$ for storm durations and precipitation magnitudes indicate similarity between the three groups (Table 2). Furthermore, a plot of storm precipitation verses time shows no statistically significant trend and the resulting regression equation is $Y = 0.0071X - 9.36$ (Figure 6 and Table 3). An additional indication of similarity results from comparing precipitation to storm duration for each storm. The resulting ratio gives a relative indication of storm intensity. Average ratios and statistical analyses for the three time groups indicate similarity (see Tables 3 and 4).

It is virtually impossible to precisely select storms that are similar in antecedent conditions due to the wide variety and spatial variations for antecedent conditions within a watershed. With a large number of storms in each group the wide variance of antecedent conditions is represented in each group increasing the similarity among the three groups and decreasing the bias from antecedent conditions. Antecedent precipitation is analyzed with other independent

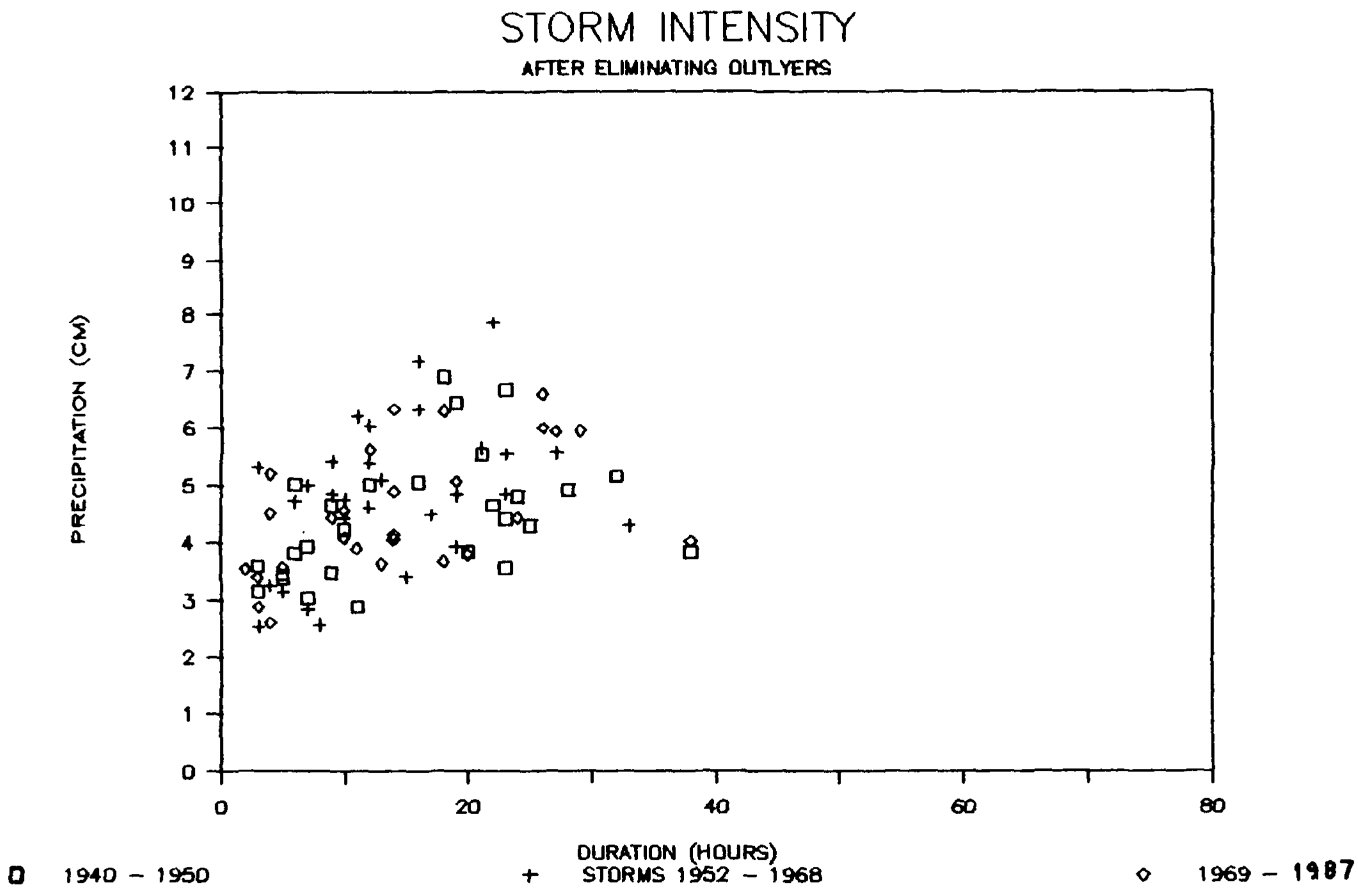

Figure 5. A plot of the 83 storm intensities after eliminating outliers and those storms not meeting antecedent precipitation criteria.

TABLE 2 STATISTICS ON THE 83 STORM SAMPLE

	MEAN	STANDARD DEVIATION	95% C.I. FOR PERIOD	F - RATIO FOR THREE PERIODS	PROBABILITY
STORM PRECIPITATION (IN CM):				0.87	0.42
TIME PERIOD 1 1940 - 1951	4.43	1.08	3.99 - 4.87		
TIME PERIOD 2 1952 - 1968	4.83	1.28	4.41 - 5.25		
TIME PERIOD 3 1969 - 1987	4.56	1.11	4.13 - 5.05		
STORM DURATION (IN HOURS):				0.44	0.64
TIME PERIOD 1 1940 - 1951	15.74	9.57	12.48 - 19.00		
TIME PERIOD 2 1952 - 1968	13.52	7.51	10.25 - 16.75		
TIME PERIOD 3 1969 - 1987	14.48	9.37	11.00 - 17.75		
RATIO (PRECIPITATION/DURATION):				0.52	0.60
TIME PERIOD 1 1940 - 1951	0.42	0.28	0.29 - 0.54		
TIME PERIOD 2 1952 - 1968	0.48	0.31	0.35 - 0.60		
TIME PERIOD 3 1969 - 1987	0.51	0.41	0.38 - 0.64		

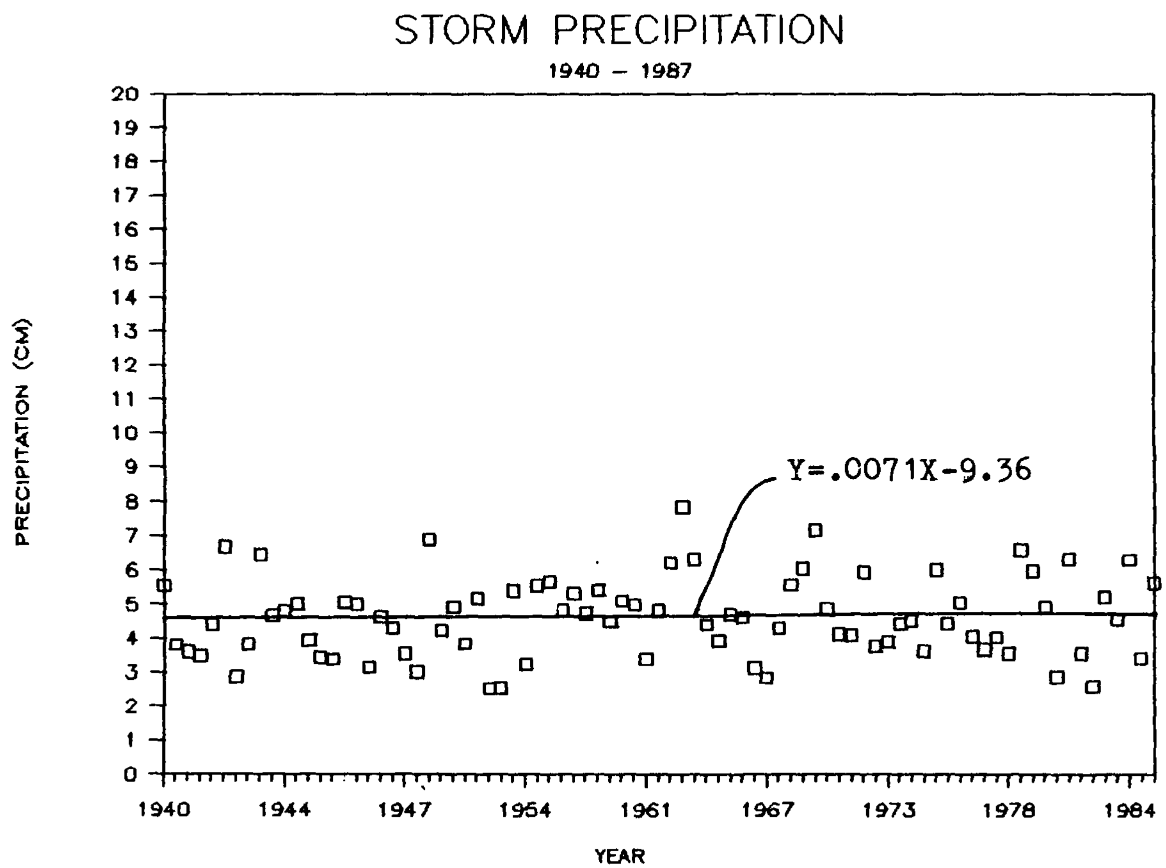

Figure 6. Precipitation amounts of the 83 storms analyzed during the study period.

TABLE 3 STATISTICS ON STORM GROUPS

A: STORM DISTRIBUTION BY PRECIPITATION AMOUNTS (IN CM)

PRECIPITATION AMOUNT:	2.50 - 4.00	4.00 - 6.00	6.00 - 8.00
TIME PERIOD 1 1940 - 1951	12	12	3
TIME PERIOD 2 1952 - 1969	7	17	5
TIME PERIOD 3 1969 - 1987	9	14	4

B: STORM DISTRIBUTION BY MONTHS

MONTHS:	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
TIME PERIOD 1 1940 - 1951	3	4	8	1	6	4	1
TIME PERIOD 2 1952 - 1969	2	3	5	6	6	4	3
TIME PERIOD 3 1969 - 1987	4	2	2	5	9	4	1

C: REGRESSION ANALYSIS - AVERAGE MONTHLY PRECIPITATION (APR - OCT) VS TIME:

CORRELATION OF THE AVERAGE MONTHLY PRECIPITATION VS TIME: 0.059

REGRESSION EQUATION: Y = 0.0071X - 9.36

STANDARD ERROR	t - VALUE (X = 0)	PROBABILITY LEVEL	F - RATIO	PROBABILITY LEVEL	R SQUARED
0.019	0.40	0.69	0.16	0.69	0.0034

TABLE 4 STORM AND HYDROGRAPH DATA

GROUP I: 1940 - 1951

DATE	YEAR	BASE FLOW CU MTRS	SURFACE RUNOFF CU MTRS	% BAS FLO	% SUR RUN	S.R.O. & B.F. CU MTRS	STORM DUR(HRs)	STORM PREC(CM)	HYDRO DUR(HRs)	TIME TO PEAK(HRs)	PEAK Q (CMS)	7 DAY ANT PREC	14 DAY ANT PREC	RATIO PRECIP/DUR
22 JUN	1940	161138	1281440	0.11	0.89	1442578	21	5.53	29	4.75	67.44	1.20	2.97	0.26
27 JUN	1940	115615	1015144	0.10	0.90	1130759	6	3.8	27	2.5	45.30	5.69	7.12	0.63
27 APR	1942	98691	408813	0.19	0.81	507504	3	3.59	22	1	22.37	0.00	0.15	1.20
31 MAY	1942	243874	1870379	0.12	0.88	2114253	9	3.46	26	11	89.18	2.23	2.69	0.38
20 JUN	1942	266915	541768	0.33	0.67	808683	23	4.41	44	8.6	19.56	0.28	1.72	0.19
1 AUG	1942	584808	6179804	0.09	0.91	6764612	23	6.66	48	26.4	174.12	2.49	4.17	0.29
7 SEP	1942	193712	550139	0.26	0.74	743851	11	2.88	40	5.3	15.09	0.90	0.69	0.26
15 MAY	1943	408326	571957	0.42	0.58	980283	20	3.83	45	13	16.45	0.07	0.22	0.19
20 OCT	1943	276499	746334	0.27	0.73	1022833	19	6.43	48	15	13.82	0.48	1.10	0.34
22 APR	1944	803041	1261167	0.39	0.61	2064208	22	4.65	88.5	21.3	26.10	0.79	3.37	0.21
12 JUN	1944	924112	1891009	0.33	0.67	2815121	24	4.8	88	15.5	37.66	2.80	5.65	0.20
27 MAY	1945	646491	2704355	0.19	0.81	3350846	12	5	37	17.6	110.70	1.88	7.61	0.42
9 JUN	1945	637315	1250110	0.34	0.66	1887425	7	3.92	47	8.7	41.90	0.24	6.76	0.56
13 AUG	1945	251571	328919	0.43	0.57	580490	5	3.43	35	3.1	11.78	0.40	1.97	0.69
31 AUG	1945	219660	717038	0.23	0.77	936698	5	3.38	31	4.5	45.44	1.73	2.00	0.68
7 SEP	1945	299745	912295	0.25	0.75	1212040	16	5.05	40	16.2	30.29	0.10	5.05	0.32
16 AUG	1946	165114	774300	0.18	0.82	939414	6	5.01	41	6.1	48.13	0.74	4.24	0.84
9 AUG	1946	112149	125500	0.47	0.53	237649	3	3.15	44	15	2.89	0.89	1.83	1.05
22 SEP	1946	206355	794615	0.21	0.79	1000970	9	4.64	44	7.5	19.25	2.34	4.86	0.52
28 MAY	1947	542905	829738	0.40	0.60	1372643	25	4.3	50	13.5	29.16	0.56	0.56	0.17
1 JUN	1947	827153	729242	0.53	0.47	1556395	23	3.55	61	16.9	15.01	5.97	8.20	0.15
28 JUN	1947	424638	254248	0.63	0.37	678886	7	3.02	35	9.3	12.60	0.74	1.38	0.43
28 AUG	1947	316363	373136	0.46	0.54	689499	18	6.89	58	19.9	9.09	0.29	0.30	0.38
4 SEP	1947	298215	1630052	0.15	0.85	1928267	10	4.23	50	8.1	86.64	6.94	7.23	0.42
27 JUN	1948	318912	533592	0.37	0.63	852504	28	4.91	46	9.1	13.00	0.28	0.47	0.18
21 JUL	1948	139881	1315534	0.10	0.90	1455415	38	3.84	28	4.1	78.14	1.06	1.54	0.10
23 APR	1950	430654	732504	0.37	0.63	1163158	32	5.16	64	5	16.37	0.39	3.10	0.16
AVERAGES:		367180	1123079	0.29	0.71	1490259	15.74	4.43	45.36	10.72	40.67	1.50	3.22	0.42

CU MTRS: cubic meters,
S.R.O.: surface runoff,
B.F.: baseflow,
DUR: duration,
PREC: precipitation,
HYDRO: hydrograph,
Q: discharge,
ANT PREC: antecedent precipitation,
PRECIP/D: storm precipitation to storm duration

TABLE 4 STORM AND HYDROGRAPH DATA

GROUP 2: 1952 - 1968

DATE	YEAR	BASE FLOW CU MTRS	SURFACE RUNOFF CU MTRS	% BAS FLO	% SUR RUN	S.R.O. & B.F. CU MTRS	STORM DUR(HRs)	STORM PREC(CM)	HYDRO DUR(HRs)	TIME TO PEAK(HRs)	PEAK Q (CMS)	7 DAY ANT PREC	14 DAY ANT PREC	RATIO PRECIP/DUR
25 JUL	1952	185556	206482	0.47	0.53	392038	3	2.54	40	5.5	6.00	4.88	5.92	0.85
15 AUG	1952	213338	643366	0.25	0.75	856704	8	2.56	45	5.5	30.86	1.80	3.26	0.32
26 JUL	1953	149260	131734	0.53	0.47	280994	12	5.39	48	13	2.10	0.21	1.45	0.45
5 APR	1954	358419	339563	0.51	0.49	697982	4	3.25	79	19	3.77	0.34	1.89	0.81
23 APR	1955	364180	512467	0.42	0.58	876647	23	5.55	76	20.3	6.43	0.75	3.01	0.24
1 JUN	1955	115310	979565	0.11	0.89	1094875	21	5.65	29	1.1	77.29	2.23	3.53	0.27
16 JUL	1957	180152	2452582	0.07	0.93	2632734	8	4.83	31	5.6	93.17	7.17	9.43	0.60
8 OCT	1958	249787	752839	0.25	0.75	1002626	3	5.31	49	4.10	25.21	2.47	3.37	1.77
19 MAY	1959	194120	1079179	0.15	0.85	1273299	10	4.75	34	5.1	42.1	0.88	4.48	0.48
3 AUG	1959	167714	513415	0.25	0.75	681129	9	5.42	47	14.8	10.28	0.41	0.52	0.60
14 AUG	1959	165165	834917	0.17	0.83	1000082	17	4.49	40	2.9	45.6	0.21	5.85	0.26
28 AUG	1960	203398	242956	0.46	0.54	446354	13	5.10	30	9	7.79	0.01	4.09	0.39
2 SEP	1961	206049	662661	0.24	0.76	868710	7	4.99	47	7.6	28.77	0.76	0.92	0.71
30 SEP	1961	566355	436154	0.56	0.44	1002509	15	3.40	55	16.3	7.96	1.89	3.87	0.23
29 OCT	1961	817264	2563524	0.24	0.76	3380788	19	4.83	48	11	99.41	1.48	2.05	0.25
29 MAY	1962	415615	1261350	0.25	0.75	1676965	11	6.21	31	7.2	47.01	1.04	1.09	0.56
1 JUL	1962	545964	1944458	0.22	0.78	2490422	22	7.85	45	15.8	82.41	0.15	2.68	0.36
18 JUL	1963	169294	1206494	0.12	0.88	1375788	15	6.33	41	10.9	54.1	3.23	4.52	0.42
20 AUG	1964	114698	197337	0.37	0.63	312035	11	4.42	45	13.5	3.63	0.57	1.03	0.40
26MAY	1965	171180	288779	0.37	0.63	459959	19	3.93	73	23.4	8.04	1.88	2.66	0.21
4SEP	1965	156295	587250	0.21	0.79	743545	7	4.71	42	7.2	18.06	3.37	8.33	0.67
8JUN	1966	229804	292903	0.44	0.56	522707	12	4.61	49	9.4	8.78	1.86	1.86	0.38
27JUN	1966	263143	106720	0.71	0.29	369863	5	3.14	58	17.7	2.75	0.97	1.98	0.63
10JUN	1967	152778	361789	0.30	0.70	514567	7	2.84	37	11.5	9.60	3.29	4.85	0.41
17JUN	1967	162209	232302	0.41	0.59	394511	33	4.3	43	8.5	9.00	4.39	7.25	0.13
7OCT	1967	242242	264061	0.48	0.52	506303	27	5.56	72	18	4.76	0.00	1.10	0.21
23JUL	1968	228785	1266550	0.15	0.85	1495335	12	6.04	68	19.25	36.86	1.01	2.42	0.50
4AUG	1968	314018	1302871	0.19	0.81	1616889	16	7.17	56	18	53.65	0.63	7.29	0.45
3SEP	1968	406796	516040	0.44	0.56	922836	23	4.84	70	21.75	9.00	2.54	5.37	0.21
AVERAGES:		265824	764838	0.32	0.68	1030662	13.52	4.83	49.24	11.84	28.77	1.74	3.66	0.48

CU MTRS: cubic meters,
S.R.O.: surface runoff,
B.F.: baseflow,
DUR: duration,
PREC: precipitation,
HYDRO: hydrograph,
Q: discharge,
ANT PREC: antecedent precipitation,
PRECIP/D: storm precipitation to storm duration

TABLE 4 STORM AND HYDROGRAPH DATA

GROUP 3: 1969 - 1987

DATE	YEAR	BASE FLOW CU MTRS	SURFACE RUNOFF CU MTRS	% BAS FLO	% SUR RUN	S.R.O. & B.F. CU MTRS	STORM DUR(HRs)	STORM PREC(CM)	HYDRO DUR(HRs)	TIME TO PEAK(HRs)	PEAK Q (CMS)	7 DAY ANT PREC	14 DAY ANT PREC	RATIO PRECIP/DUR
4JUN	1969	198198	143704	0.58	0.42	341902	14	4.14	48	19.5	7.16	0.60	2.42	0.30
4SEP	1971	134171	99711	0.57	0.43	233882	10	4.08	56	22	2.15	1.03	1.52	0.41
27MAY	1973	1382497	1251308	0.52	0.48	2633805	27	5.94	60	21.25	31.82	1.50	1.60	0.22
3JUL	1973	579915	540662	0.52	0.48	1120577	20	3.79	48	9	23.61	0.09	1.11	0.19
21SEP	1973	318096	588632	0.35	0.65	906728	11	3.9	40	7.25	17.98	1.00	2.63	0.35
10AUG	1974	503143	354188	0.59	0.41	857331	24	4.43	42	12	7.59	0.70	1.97	0.18
16AUG	1974	260288	208241	0.56	0.44	468529	4	4.51	23	9	5.18	4.92	5.76	1.13
21AUG	1974	341138	204214	0.63	0.37	545352	13	3.63	28	9	9.20	1.23	9.82	0.28
27APR	1975	1004655	1269379	0.44	0.56	2274034	26	6.01	52	13	24.46	1.16	1.72	0.23
9AUG	1975	183313	128258	0.59	0.41	311571	9	4.43	31	18	2.55	0.46	0.66	0.49
29AUG	1975	204519	207935	0.50	0.50	412454	19	5.06	34	17	5.80	5.15	5.78	0.27
5OCT	1976	134171	63925	0.68	0.32	198096	14	4.06	50	32	1.64	0.00	0.08	0.29
5APR	1978	437383	248156	0.64	0.36	685539	18	3.67	33	6	9.12	0.63	1.09	0.20
18APR	1978	386915	146304	0.73	0.27	533219	38	4.03	30	18	7.53	0.53	6.44	0.11
6JUL	1978	199524	187136	0.52	0.48	386660	2	3.54	19	3.25	14.61	4.43	6.11	1.77
20JUL	1978	301427	1037587	0.23	0.77	1339014	26	6.59	27	7.75	57.25	1.21	6.28	0.25
17SEP	1978	266406	660662	0.29	0.71	927068	29	5.96	39	15.5	17.47	3.77	3.77	0.21
3JUL	1979	252489	775373	0.25	0.75	1027862	14	4.89	39	12.25	19.93	0.94	2.87	0.35
30JUL	1979	157723	257383	0.38	0.62	415106	3	2.88	26	11.75	7.73	1.95	4.70	0.96
17AUG	1979	428971	1940084	0.18	0.82	2369055	14	6.33	45	14.25	74.01	0.35	6.91	0.45
15JUN	1980	222565	361554	0.38	0.62	584119	5	3.56	37	7.25	7.70	0.35	4.96	0.71
7AUG	1981	153338	13457	0.92	0.08	166795	4	2.6	32	4	1.67	1.36	1.67	0.65
25AUG	1983	548105	286911	0.66	0.34	835016	4	5.2	84	8.25	6.74	0.66	0.74	1.30
29APR	1984	579507	604435	0.49	0.51	1183942	10	4.55	56	8	14.01	0.48	1.38	0.46
24SEP	1984	348887	317497	0.52	0.48	666384	18	6.29	58	7.75	6.34	0.20	0.51	0.35
14MAY	1987	222897	115144	0.66	0.34	338041	3	3.39	26.5	7.75	7.67	0.05	1.35	1.13
8AUG	1987	423389	381346	0.53	0.47	804735	12	5.62	56.5	13.5	8.64	0.51	3.56	0.47
AVERAGES:	1987	376801	459007	0.52	0.48	835808	14.48	4.56	41.48	12.38	14.80	1.30	3.22	0.51

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ANT PREC: antecedent precipitation,
PRECIP/D: storm precipitation to storm duration

variables utilizing regression analysis.

LAND USE

Land use was evaluated by estimating from aerial photographs the percentages of a given land use observed along line transects drawn across the Galena watershed at specified intervals. Twelve transects spaced approximately two kilometers apart and oriented in a predominantly east/west direction provided adequate spatial coverage to ensure a representative sample of lower order streams and headwaters (Figure 3). Scale differences between photograph series were not a bias as this analysis is based on relative percentages. The large scale of the aerial photographs allowed three land use classifications: cultivated, non-cultivated, and forested. A further division of the cultivated land into that with soil conservation practices verses that with no soil conservation practices was also undertaken. Classification of row crops and most other small scale land uses were not possible due to the scale and clarity of the aerial photographs. Existing agricultural statistics describe agricultural land use on a county level prohibiting a specific analysis of the Galena watershed. All known aerial photography taken during this study period was analyzed. These included photographs for the following years: 1937, 1951, 1955, 1962, 1968, 1976, and 1985.

Table 5 summarizes the changing land use within the Galena watershed from 1937 through 1985. All photographic series except the 1951 and 1968 series were taken from late August to late October (see Table 5). The possible bias introduced from analyzing photographs from different seasons is minimal due to the broad land use classification categories and to the ease in identifying soil conservation practices such as strip cropping and contour plowing. One possible bias from analyzing photographs from different seasons might occur as leaf cover appears greater in autumn than spring. The fluctuating percentage of forested land may be biased, although the 1985 series does not conform to this bias. The small percentage of forested land throughout the study period decreased the significance of this possible bias.

Land use varies from north to south within the Galena watershed. The northern portion of the Galena watershed has less relief and is characterized by large, gently sloping, cultivated fields utilizing less soil conservation practices than in fields of the steeper southern portion. The majority of cultivation occurs in the northern portion while the southern portion has the

TABLE 5 LAND USE 1937 - 1985

DATE OF AERIAL PHOTOGRAPHS	PERCENT CULTIVATED	PERCENT NON-CULTIVATED	PERCENT FOREST	PERCENT OF CULTIVATED LAND UNDER SOIL CONSERVATION PRACTICES	SCALE OF PHOTOGRAP
29-30 OCT 1937	51	38	11	00	1:20,000
26 APRIL 1951	52	42	06	07	1:17,000
4-5 SEP 1955	51	41	08	10	1:20,000
28 AUG 1962	54	37	09	13	1:20,000
12 MAY 1968	54	40	06	17	1:20,000
9-10 SEP 1976	50	40	10	27	1:40,000
AUTUMN 1985	54	40	06	38	1:15,840

majority of forested land.

The 1937 and 1951 aerial photographs indicate minimal use of soil conservation practices (Table 5 and Figure 7). Cultivated fields, especially those in the southern part of the watershed, indicate extensive gullying and soil erosion. Forests appear sparse compared to that shown on later aerial photograph series. Overall, the land use from 1937 to 1951 indicates poor conservation practices.

From 1955 through 1968 adoption of soil conservation practices increased. Gullying appears less extensive and headward erosion of channels appears to subside. Forests appear more dense. The influence of improved agricultural technology is suggested during this time period as the 1937 photographs indicated corn shocks geometrically spaced in denuded and harvested fields while the 1955 and later photographs are devoid of any indication of corn shocks.

The latest period indicates a substantial increase in the use of soil conservation practices. Gullying exists, but is at its lowest activity level since the late 1930s and 1940s and is characterized by minimal headward erosion. The quality of soil conservation practices appears to improve during this period as contour farming is more precise, strip cropping is more

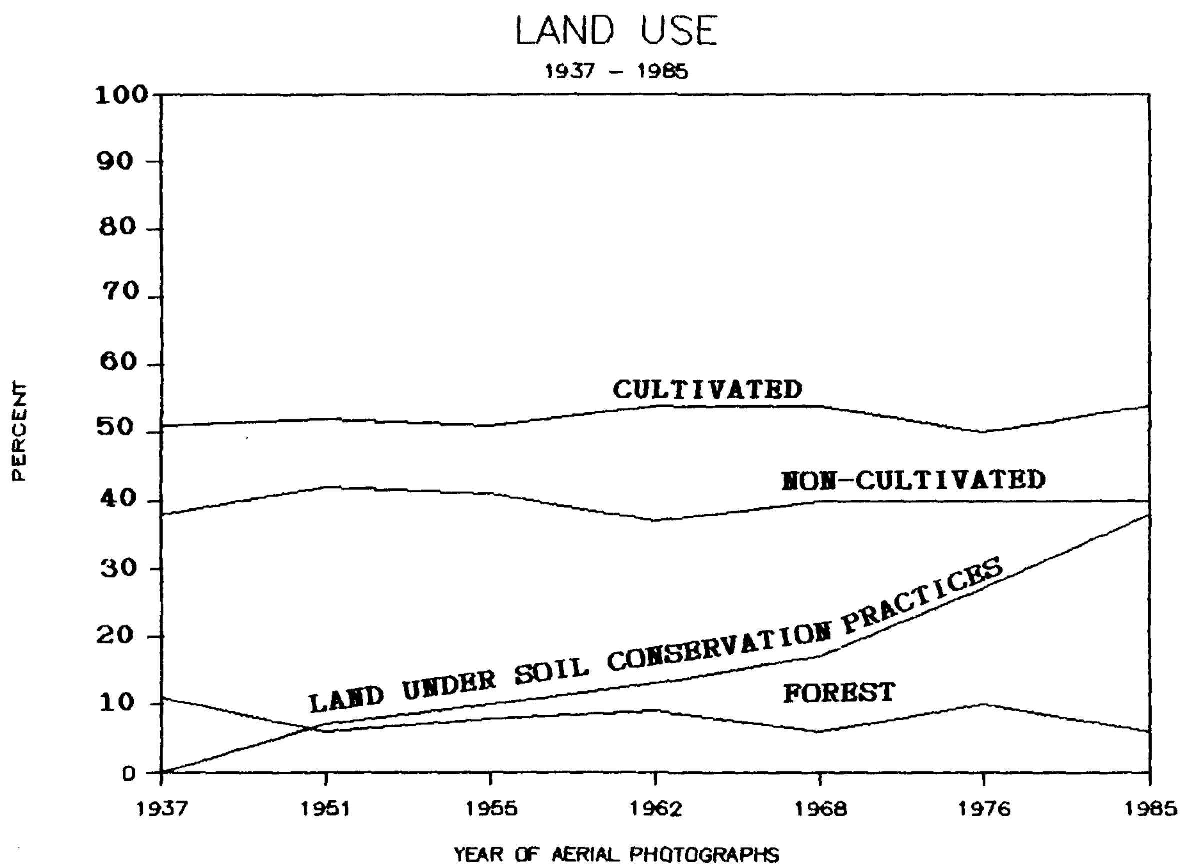

Figure 7. Fluctuating percentages of land use from 1937 through 1985 determined from aerial photography analyses.

frequent, and the use of buffer strips around fields is more apparent.

Soil conservation practices in the Galena watershed consist primarily of strip cropping and contour farming. From 1937 through 1962 strip cropping and contour farming were the only conservation practices observed. Beginning in 1968, indications of terracing and buffer strips around fields began to appear in addition to previous cultivation conservation practices.

Several federal and state programs initiated since the mid-1960s appear to have had minimal influence on the significant increase in soil conservation within the Galena watershed since the late 1960s. In 1965 the Agriculture Stabilization and Conservation Service (A.S.C.S.) initiated the Soil Bank Program which gave farmers federal subsidies for taking cultivated land in erosion prone areas out of cultivation for a period of 10 years. The program exists today as the Conservation Reserve Program (CRP). The hydrologic influence of the Soil Bank and CRP programs on the Galena watershed is insignificant as less than one percent of the watershed area participated in the programs during the study period (conversation with Lafayette County A.S.C.S. Executive Director Leon Wolfe, December, 1989).

The Galena watershed received State funding during the early 1970s to construct terraces in highly erodible areas. Statistics defining the amount of terracing constructed within the Galena watershed do not exist. Terracing is difficult to differentiate from contour farming on aerial photographs, prohibiting a precise evaluation of its significance since the early 1970s. However, the amount of terracing within the Galena watershed is estimated to be less than five percent of the area utilizing soil conservation practices (conversation with Lafayette County A.S.C.S. Executive Director Leon Wolfe, December 1989).

The most probable factor influencing the increase in soil conservation since the late 1960s is the farmer's awareness and understanding of soil conservation practices. A previous study by Johansen (1969) illustrates the rapid rate farmers adopted contour strip cropping from 1939 (233 users) to 1967 (6402 users) in southwestern Wisconsin as they became aware of the methods and benefits of soil conservation.

Farmers have also responded to the landmark 1985 Federal Food Security Act which mandates the use of soil conservation practices as a prerequisite to receiving Federal subsidies. Federal subsidies are extremely important to most farmers and may account for a significant portion of their financial income.

Lafayette County A.S.C.S. Executive Director Leon Wolfe estimates that 85-90% of the cultivated land within the Galena watershed will involve soil conservation practices by 1995 as a consequence of the Federal Food Security Act.

ESTIMATED SURFACE RUNOFF AND BASEFLOW

Hydrograph data representing runoff from the 83 sample storms were obtained from the U.S.G.S. Water Resources Division archives. The U.S.G.S. gaging station located on the Galena River at Buncombe, Wisconsin operated from 1940 until July 1967 with a Friez FA-3 water-stage recorder which produced a paper strip chart indicating the actual water stage of the river in feet (U.S.G.S. Station Analysis, 1940 - 1987). A rating curve converts the water stage to discharge and is updated periodically as the channel geometry changes. In July 1967 the U.S.G.S. installed a Fischer-Porter digital recorder which records the water depth every 15 minutes in a digital format eliminating the paper strip chart. Since 1986, the U.S.G.S. instituted a computerized system that instantaneously applies the rating curve to the digital depth to produce a record of discharge in cubic feet per second every 15 minutes.

The U.S.G.S. prepares an annual station analysis describing the water year for each gage. The station analysis defines periods when shifts in the relationship between gage height and discharge have occurred. Shifts may occur due to changes in the channel geometry at the gaging station. All applicable shifts were applied to the hydrographs analyzed in this study.

Each hydrograph was quantified to obtain accurate percentages of surface runoff and baseflow from storm events. The strip chart data or digital hydrograph data were converted into discharge using the rating curves. The discharge data were then converted into an (X,Y) coordinate, the X-axis representing time in hours and the Y-axis representing discharge. This process produced a data file containing (X,Y) coordinates that were used to quantify both surface runoff and baseflow for the storms analyzed. The portion of the hydrograph representing surface runoff was determined by a visual inspection of the hydrograph data as previously discussed.

Data files describing surface runoff and baseflow were processed through a Fortran computer program that determines the areas of irregularly shaped polygons (Appendix 1). The computer program determined the areas under the hydrograph curve representing surface runoff and baseflow. The area determined by the Fortran program equated to a volume as discharge (defining the Y axis in CMS) was multiplied by time (defining the X axis in hours) (Table 4). The Fortran program converted the hours to seconds and produced a final output in cubic meters which facilitated calculating the percent of surface runoff and base flow.

The estimated percentages of surface runoff and baseflow appear by time periods in Table 4. Figures 8 and 9 illustrate trends for the estimated percentages of surface runoff and baseflow during the three time intervals of the study period. The results indicate the relative fraction of total runoff that is surface runoff has decreased from the 1940s through 1980s. Baseflow shows an opposite trend. Table 6 summarizes results from regression analyses performed on estimated surface runoff and baseflow percentages during the study period and within the three time periods. The surface runoff regression line for the study period is $Y = -0.0064X + 13.34$; baseflow: $Y= 0.0064X - 12.34$. These statistical relationships are significant at the 0.0000 probability level (see Table 6). The variances explained by the two equations are low ($r^2 = 0.24$), which is evident by visual inspection of Figures 8 and 9. Separate regression analyses for the three time

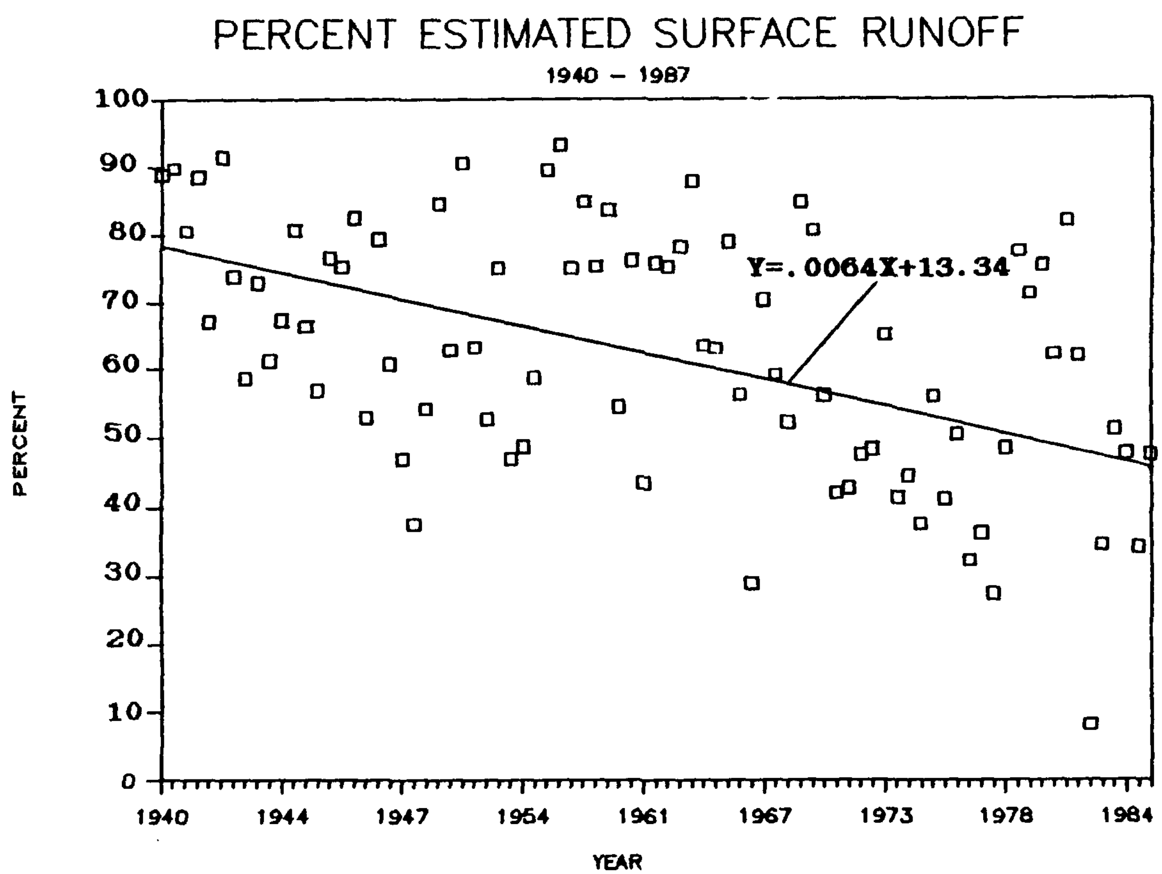

Figure 8. The estimated percent of total runoff that is surface runoff for the 83 analyzed storms.

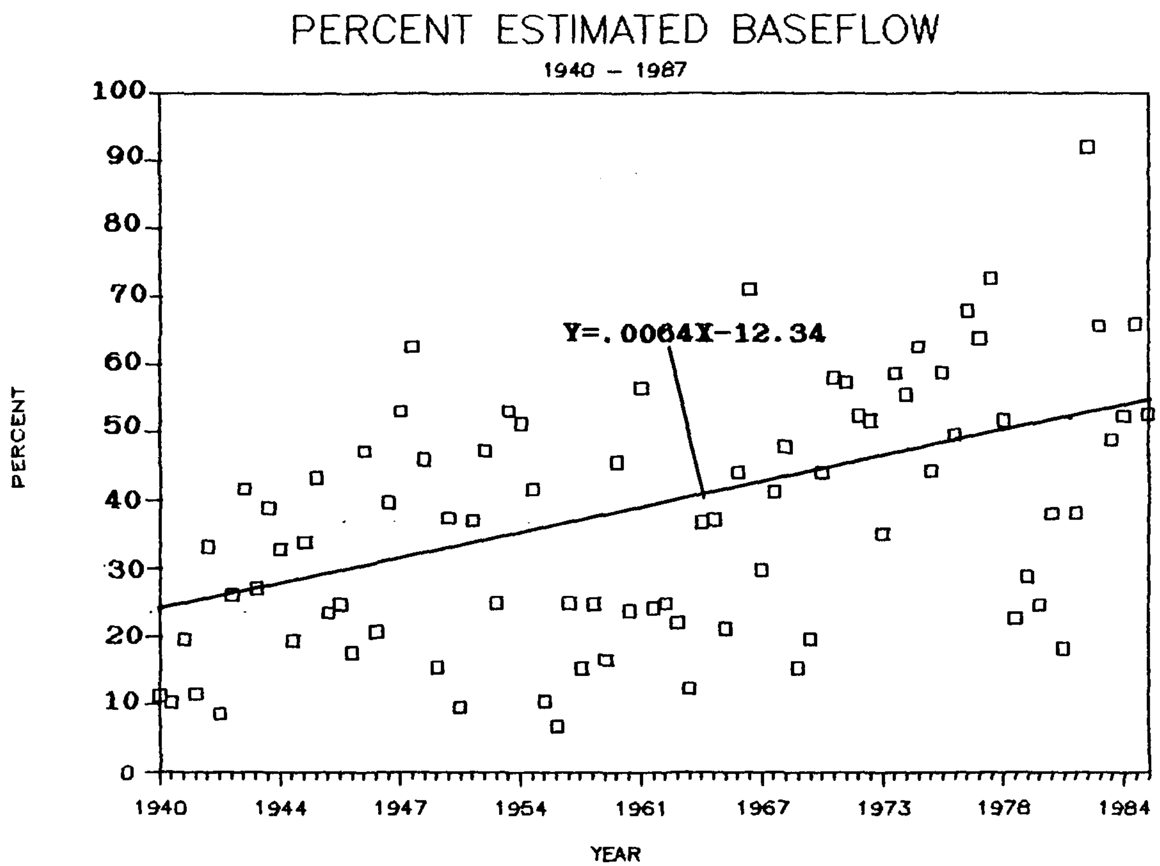

Figure 9. The estimated percent of total runoff that is baseflow for the 83 analyzed storms.

TABLE 6 - SURFACE RUNOFF, BASEFLOW, AND TOTAL RUNOFF VERSUS TIME
FROM 1940 - 1987

CORRELATION OF THE PERCENT OF SURFACE RUNOFF VS TIME: -0.4944
CORRELATION OF THE PERCENT OF BASEFLOW VS TIME: 0.4944
CORRELATION OF THE TOTAL RUNOFF VS TIME: -0.2861

REGRESSION EQUATIONS:		STANDARD ERROR	t-VALUE (X = 0)	PROB LEVEL	F-RATIO	PROB LEVEL	R SQUARED
PERCENT OF SURFACE RUNOFF:	Y = -0.0064X + 13.34	0.0013	-5.12	0.0000	26.2	0.0000	0.2444
PERCENT OF BASEFLOW:	Y = 0.0064X - 12.34	0.0013	5.12	0.0000	26.2	0.0000	0.2444
TOTAL RUNOFF:	Y = -19530.66X + 3.94E+7	7266.39	-2.69	0.0087	7.22	0.0087	0.0819

REGRESSION ANALYSIS OF INDEPENDENT VARIABLES
FROM 1940 - 1987

REGRESSION ANALYSIS SURFACE RUNOFF VS INDEPENDENT VARIABLES:	F - RATIO	PROBABILITY LEVEL	R SQUARED
	13.06	0.0000	0.5989

CORRELATIONS

	STORM DURATION	STORM PRECIP	HYDRO DURATION	TIME TO PEAK	PEAK Q	7 DAY ANT PRE	14 DAY ANT PRE	RATIO PREC/DUR	%SURFACE RUNOFF
STORM DURATION	1.0000	0.3901	0.1913	0.2725	0.1621	-0.1016	-0.0339	-0.7495	0.0783
STORM PRECIP	0.3901	1.0000	0.2027	0.2643	0.3629	-0.1572	-0.0352	-0.1915	0.3915
HYDRO DURATION	0.1913	0.2027	1.0000	0.5394	-0.1620	-0.1671	-0.1935	-0.1719	-0.1349
TIME TO PEAK	0.2725	0.2643	0.5394	1.0000	-0.0206	-0.1310	-0.0902	-0.3139	-0.1822
PEAK DISCHARGE	0.1621	0.3629	-0.1620	-0.0206	1.0000	0.2053	0.2696	-0.1498	0.7020
7 DAY ANT PRECIP	-0.1016	-0.1572	-0.1671	-0.1310	0.2053	1.0000	0.6111	0.1546	0.2149
14 DAY ANT PRECIP	-0.0339	-0.0352	-0.1935	-0.0902	0.2696	0.6111	1.0000	0.0433	0.2705
RATIO PREC/DUR	-0.7495	-0.1915	-0.1719	-0.3139	-0.1498	0.1546	0.0433	1.0000	-0.0988
% SURFACE RUNOFF	0.0783	0.3915	-0.1349	-0.1822	0.7020	0.2149	0.2705	-0.0988	1.0000

REGRESSION ANALYSIS
DEPENDENT VARIABLE: PERCENT SURFACE RUNOFF

INDEPENDENT VARIABLES:	PARAMETER ESTIMATE	STDIZED ESTIMATE	STDARD ERROR	t-VALUE (X=0)	PROBILTY LEVEL	SIMPLE R SQR	PARTIAL R SQR
INTERCEPT	0.4527	0.0000	0.0868	5.2100	0.0000		
STORM DURATION	-0.0045	-0.2174	0.0026	-1.7425	0.0858	0.0061	0.0416
STORM PRECIP	0.0483	0.3067	0.0150	3.2193	0.0019	0.1530	0.1290
HYDRO DURATION	0.0009	0.0810	0.0011	0.8669	0.3878	0.0182	0.0107
TIME TO PEAK	-0.0089	-0.2341	0.0029	-3.0041	0.0037	0.0332	0.1142
PEAK DISCHARGE	0.0033	0.5551	0.0005	6.3186	0.0000	0.4928	0.3632
7 DAY ANT PRECIP	0.0104	0.0950	0.0108	0.9534	0.3387	0.0462	[illegible]
14 DAY ANT PRECIP	0.0047	0.0621	0.0074	0.6332	0.5286	0.0732	0.0057
RATIO PREC/DUR	-0.1167	[illegible]	0.0673	-1.7340	0.0873	0.0098	0.0412

TABLE 6 REGRESSION ANALYSIS - SURFACE RUNOFF AND BASEFLOW VERSUS TIME
FROM 1940 - 1951

CORRELATION OF THE PERCENT OF SURFACE RUNOFF VS TIME. -0.4545

REGRESSION EQUATION:	STANDARD ERROR	t-VALUE (X = 0)	PROB LEVEL	F-RATIO	PROB LEVEL	R SQUARED
PERCENT OF SURFACE RUNOFF. Y = -0.026X + 51.03	0.01	-2.55	0.0172	6.51	0.017	0.2066

REGRESSION ANALYSIS OF INDEPENDENT VARIABLES
FROM 1940 - 1950

REGRESSION ANALYSIS SURFACE RUNOFF VS INDEPENDENT VARIABLES:	F - RATIO	PROBABILITY LEVEL	R SQUARED
	6.26	0.001	0.7578

CORRELATIONS

	STORM DURATION	STORM PRECIP	HYDRO DURATION	TIME TO PEAK	PEAK Q	7 DAY ANT PRE	14 DAY ANT PRE	RATIO PREC/DUR	%SURFACE RUNOFF
STORM DURATION	1.0000	0.3756	0.3696	0.1924	0.0558	-0.1659	-0.2454	-0.8645	0.0153
STORM PRECIP	0.3756	1.0000	0.2844	0.4703	0.2558	-0.1885	-0.0763	-0.2994	0.2664
HYDRO DURATION	0.3696	0.2844	1.0000	0.5226	-0.2356	0.0283	0.1278	-0.3473	-0.3920
TIME TO PEAK	0.1924	0.4703	0.5226	1.0000	0.2406	-0.0364	0.0540	-0.2439	-0.1917
PEAK DISCHARGE	0.0558	0.2558	-0.2356	0.2406	1.0000	0.3227	0.3543	-0.0933	0.7215
7 DAY ANT PRECIP	-0.1659	-0.1885	0.0283	-0.0364	0.3227	1.0000	0.7005	0.0335	0.2833
14 DAY ANT PRECIP	-0.2454	-0.0763	0.1278	0.0540	0.3543	0.7005	1.0000	0.1105	0.3029
RATIO PREC/DUR	-0.8645	-0.2994	-0.3473	-0.2439	-0.0933	0.0335	0.1105	1.0000	0.0197
% SURFACE RUNOFF	0.0153	0.2664	-0.3920	-0.1917	0.7215	0.2833	0.3029	0.0197	1.0000

REGRESSION ANALYSIS
DEPENDENT VARIABLE: PERCENT SURFACE RUNOFF

INDEPENDENT VARIABLES:	PARAMETER ESTIMATE	STDIZED ESTIMATE	STDARD ERROR	t-VALUE (X=0)	PROBILTY LEVEL	SIMPLE R SQR	PARTIAL R SQR
INTERCEPT	0.4453	0.0000	0.1530	2.9100	0.0101		
STORM DURATION	0.0020	0.1278	0.0044	0.4500	0.6573	0.0002	0.0126
STORM PRECIP	0.0504	0.3573	0.0219	2.3000	0.0356	0.0710	0.2478
HYDRO DURATION	-0.0011	-0.1213	0.0018	-0.5100	0.5475	0.1537	0.0231
TIME TO PEAK	-0.0107	-0.4497	0.0042	-2.5000	0.0204	0.0363	0.2817
PEAK DISCHARGE	0.0025	0.6550	0.0007	3.6900	0.0020	0.5206	0.4556
7 DAY ANT PRECIP	0.0053	0.0683	0.0141	0.3800	0.7104	0.0803	0.0089
14 DAY ANT PRECIP	0.0063	0.1069	0.0116	0.5500	0.5902	0.0918	0.0135
RATIO PREC/DUR	0.0826	0.1324	0.1609	0.5100	0.6144	0.0004	0.0162

TABLE 6 REGRESSION ANALYSIS - SURFACE RUNOFF AND BASEFLOW VERSUS TIME
FROM 1952 - 1968

CORRELATION OF THE PERCENT OF SURFACE RUNOFF VS TIME: -0.0372

REGRESSION EQUATION:	STANDARD ERROR	t-VALUE (X = 0)	PROB LEVEL	F - RATIO	PROB LEVEL	R SQUARED
PERCENT OF SURFACE RUNOFF. Y = -0.0012X + 2.35	0.006	-0.19	0.8481	0.04	0.848	0.0014

REGRESSION ANALYSIS OF INDEPENDENT VARIABLES
FROM 1952 - 1968

REGRESSION ANALYSIS SURFACE RUNOFF VS INDEPENDENT VARIABLES:	F - RATIO	PROBABILITY LEVEL	R SQUARED
	5.55	0.001	0.7002

CORRELATIONS

	STORM DURATION	STORM PRECIP	HYDRO DURATION	TIME TO PEAK	PEAK Q	7 DAY ANT PRE	14 DAY ANT PRE	RATIO PREC/DUR	%SURFACE RUNOFF
STORM DURATION	1.0000	0.3742	0.1276	0.2310	0.1986	-0.0403	0.1505	-0.6980	0.0582
STORM PRECIP	0.3742	1.0000	-0.0879	0.0854	0.5042	-0.2891	-0.0543	-0.0233	0.4935
HYDRO DURATION	0.1276	-0.0879	1.0000	0.8351	-0.3940	-0.2830	-0.2571	-0.0373	-0.4279
TIME TO PEAK	0.2310	0.0854	0.8351	1.0000	-0.3435	-0.3210	-0.2543	-0.2704	-0.4504
PEAK DISCHARGE	0.1986	0.5042	-0.3940	-0.3435	1.0000	0.1746	0.2142	-0.0915	0.7325
7 DAY ANT PRECIP	-0.0403	-0.2891	-0.2830	-0.3210	0.1746	1.0000	0.6860	0.1142	0.1908
14 DAY ANT PRECIP	0.1505	-0.0543	-0.2571	-0.2543	0.2142	0.6860	1.0000	-0.0567	0.2833
RATIO PREC/DUR	-0.6980	-0.0233	-0.0373	-0.2704	-0.0915	0.1142	-0.0567	1.0000	0.0441
% SURFACE RUNOFF	0.0582	0.4935	-0.4279	-0.4504	0.7325	0.1908	0.2833	0.0441	1.0000

REGRESSION ANALYSIS
DEPENDENT VARIABLE: PERCENT SURFACE RUNOFF

INDEPENDENT VARIABLES:	PARAMETER ESTIMATE	STDIZED ESTIMATE	STDARD ERROR	t-VALUE (X=0)	PROBILTY LEVEL	SIMPLE R SQR	PARTIAL R SQR
INTERCEPT	0.3627	0.0000	0.1455	2.6300	0.0165		
STORM DURATION	-0.0091	-0.4097	0.0054	-1.6600	0.1084	0.1034	0.1299
STORM PRECIP	0.0739	0.6014	0.0292	2.5300	0.0203	0.2435	0.2523
HYDRO DURATION	0.0050	0.4401	0.0034	1.4700	0.1566	0.1831	0.1027
TIME TO PEAK	-0.0172	-0.6619	0.0073	-2.1500	0.0447	0.2029	0.1956
PEAK DISCHARGE	0.0020	0.3702	0.0009	2.0100	0.0584	0.5366	0.1759
7 DAY ANT PRECIP	0.0161	0.1589	0.0200	0.8000	0.4333	0.0364	0.0326
14 DAY ANT PRECIP	0.0066	0.0973	0.0124	0.5400	0.5977	0.0803	0.0149
RATIO PREC DUR	-0.1339	-0.2719	0.1201	-1.4500	0.1627	0.0019	0.0959

TABLE 6 REGRESSION ANALYSIS - SURFACE RUNOFF AND BASEFLOW VERSUS TIME
FROM 1969 - 1987

CORRELATION OF THE PERCENT OF SURFACE RUNOFF VS TIME: -0.0405

REGRESSION EQUATION:	STANDARD ERROR	t-VALUE (X = 0)	PROB LEVEL	F - RATIO	PROB LEVEL	R SQUARED
PERCENT OF SURFACE RUNOFF: $Y = -0.0015 + 3.35$	0.0072	-0.2	0.8411	0.04	0.841	0.0016

REGRESSION ANALYSIS OF INDEPENDENT VARIABLES
FROM 1952 - 1968

REGRESSION ANALYSIS SURFACE RUNOFF VS INDEPENDENT VARIABLES:	F - RATIO	PROBABILITY LEVEL	R SQUARED
	2.8	0.035	0.5687

CORRELATIONS

	STORM DURATION	STORM PRECIP	HYDRO DURATION	TIME TO PEAK	PEAK Q	7 DAY ANT PRE	14 DAY ANT PRE	RATIO PREC/DUR	%SURFACE RUNOFF
STORM DURATION	1.0000	0.5117	0.0983	0.4415	0.3096	-0.0686	0.0497	-0.7638	0.1578
STORM PRECIP	0.5117	1.0000	0.4462	0.3096	0.5814	0.0234	0.0012	-0.3344	0.5300
HYDRO DURATION	0.0983	0.4462	1.0000	0.2545	0.0294	-0.3993	-0.5289	-0.1624	-0.0240
TIME TO PEAK	0.4415	0.3096	0.2545	1.0000	0.0275	0.0014	-0.0514	-0.4610	0.0835
PEAK DISCHARGE	0.3096	0.5814	0.0294	0.0275	1.0000	-0.1149	0.3037	-0.2026	0.6701
7 DAY ANT PRECIP	-0.0686	0.0234	-0.3993	0.0014	-0.1149	1.0000	0.4153	0.3269	0.0996
14 DAY ANT PRECIP	0.0497	0.0012	-0.5289	-0.0514	0.3037	0.4153	1.0000	0.0861	0.2827
RATIO PREC/DUR	-0.7638	-0.3344	-0.1624	-0.4610	-0.2026	0.3269	0.0861	1.0000	-0.1505
% SURFACE RUNOFF	0.1578	0.5300	-0.0240	0.0835	0.6701	0.0996	0.2827	-0.1505	1.0000

REGRESSION ANALYSIS
DEPENDENT VARIABLE: PERCENT SURFACE RUNOFF

INDEPENDENT VARIABLES:	PARAMETER ESTIMATE	STDIZED ESTIMATE	STDARD ERROR	t-VALUE (X=0)	PROBILTY LEVEL	SIMPLE R SQR	PARTIAL R SQR
INTERCEPT	0.3403	0.0000	0.1754	1.9400	0.0691		
STORM DURATION	-0.0074	-0.4290	0.0049	-1.4900	0.1542	0.0249	0.1157
STORM PRECIP	0.0607	0.4127	0.0429	1.4200	0.1744	0.2809	0.1057
HYDRO DURATION	-0.0019	[illegible]	0.0028	-0.6700	0.5092	0.0006	0.0260
TIME TO PEAK	0.0013	0.0413	0.0061	0.2100	0.8336	0.0070	0.0027
PEAK DISCHARGE	0.0051	0.5146	0.0023	2.1500	0.0464	0.4490	0.2135
7 DAY ANT PRECIP	0.0152	[illegible]	0.0254	0.6000	0.5589	0.0099	0.0205
14 DAY ANT PRECIP	0.0019	0.0283	0.0144	0.1300	0.8970	0.0739	0.0010
RATIO PREC/DUR	[illegible]	[illegible]	0.1139	-1.0200	0.3225	0.0225	0.0576

periods indicate the sharpest decline in surface runoff occurred from 1940 to 1952 with moderate declines in the later two groups (Table 6 and Figure 8). The statistical relationships and small explained variances for all groups, especially the later two, are not significant. Nevertheless, all analyses suggest a significant decrease in surface runoff from the 1940s to the 1980s.

MULTIPLE REGRESSION ANALYSIS

Multiple regression analysis was used to explore long-term historical trends in surface runoff and baseflow with trends in other hydrologic and climatic factors (Table 6). An analysis of the average monthly precipitation and temperature form April through October for each year of the study period indicates wide and random fluctuations (precipitation r^2=0.003, temperature r^2=0.019) (Figure 10 and 11). Analyses showed no statistical significance and therefore no trends in the slopes of the regression lines for both precipitation and temperature. The monthly average precipitation data from April through October were derived from the previously discussed four weather stations using the Thiessen method. Temperature data are from the Darlington station which has the only

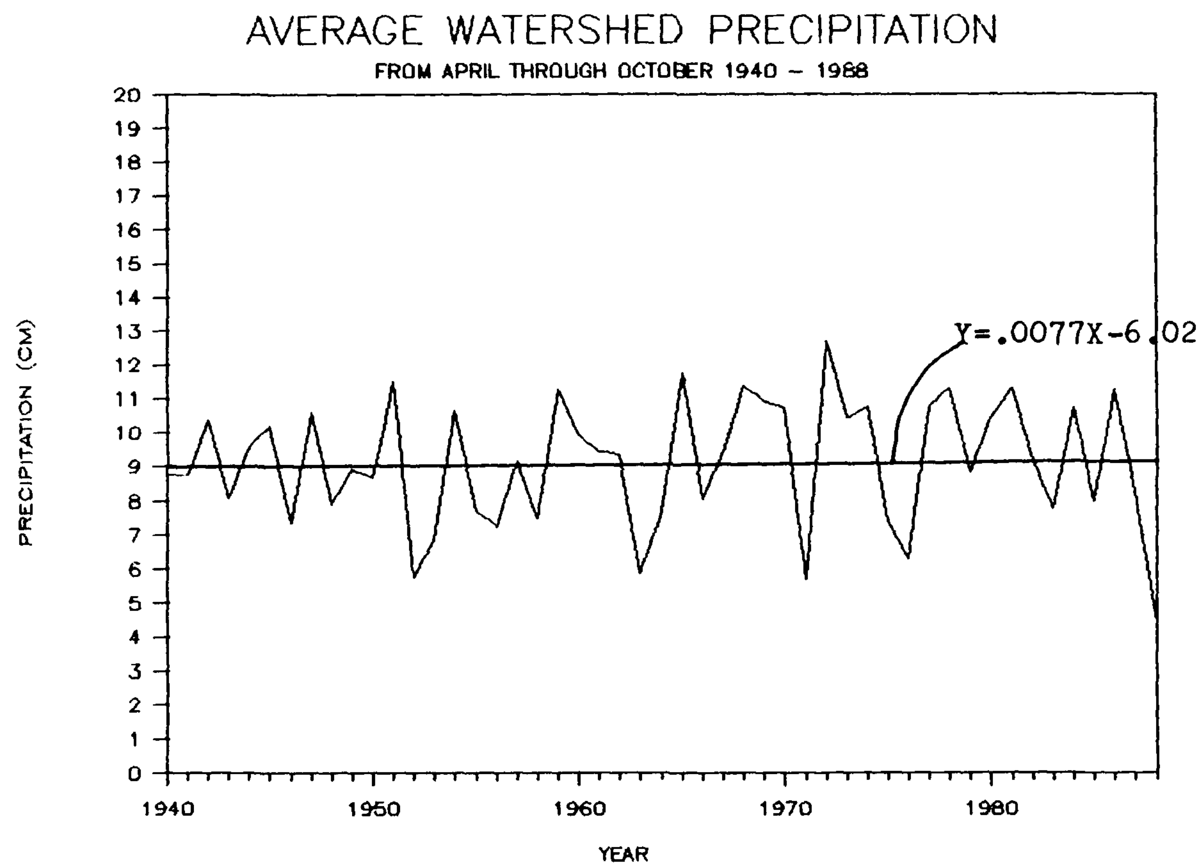

Figure 10. Average monthly precipitation from April through October for each year of the study period. The precipitation average was determined from four weather stations using the Thiessen Polygon method.

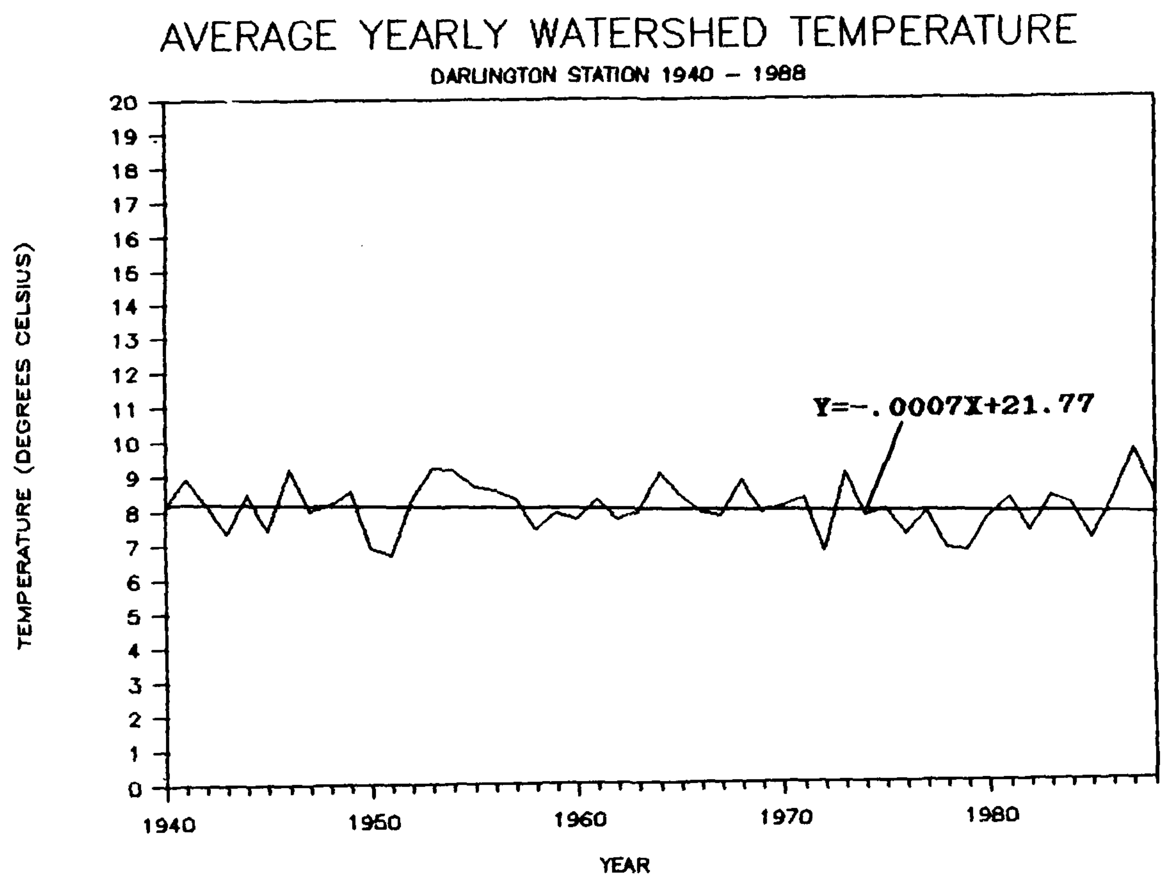

Figure 11. Average monthly temperature from April through October for each year of the study period determined from the Darlington weather station.

continuous temperature record for the study period. The lack of change in precipitation and temperature with time indicate that climatic factors are not responsible for the observed historical trend in surface runoff and baseflow.

Multiple regression analyses were used for evaluating climatic influences on runoff. Storm and runoff characteristics constitute the independent variables analyzed in relation to the estimated surface runoff dependent variable. The independent variables are: 1. storm precipitation, 2. storm duration, 3. estimated surface runoff duration, 4. the time from the beginning of surface runoff to the peak discharge, 5. peak discharge, 6. preceding seven days antecedent precipitation, 7. preceding fourteen days antecedent precipitation, and 8. storm intensity ratio (used earlier to evaluate similarity between storm groups) (Table 4).

Durations of surface runoff were estimated from gage strip charts or from tables of gage heights by identifying the time between the initial point of rise and the asymtotic stabilization point on the recession limb. Time to peak data was determined by measuring the time from the beginning of surface runoff to the time the highest peak observed on the hydrograph. This method was used instead of measuring from the centroid of rainfall to the centroid of the hydrograph due to the inaccuracy of the rainfall centroid. The rainfall centroid is inaccurate due to the use of the Thiessen method and having only one hourly recording precipitation station. Many hydrographs have multiple peaks. To ensure consistency the highest magnitude peak was used to determine estimates of the time to peak and peak discharge variables. Use of the highest magnitude hydrograph peak is desired for consistency and introduced slight fluctuations in the time to peak data.

The Thiessen method was used to determine both antecedent precipitation variables. The definition of the seven-day antecedent precipitation was based on recommendations given in the National Engineering Handbook and by hydrologists of the U.S. Soil Conservation Service (S.C.S.) (Mockus, 1972 and phone conservation with John Milligan, S.C.S., Madison, WI, June 1989). The National Engineering Handbook establishes a criteria of five days of no antecedent precipitation to achieve maximum infiltration capacity while hydrologists at the Wisconsin S.C.S. believe at least seven days are needed. Following the same procedures and logic, a fourteen-day antecedent precipitation criterion was used to evaluate longer-term influences.

Table 6 summarizes the results of the multiple regression analysis. Results indicate weak correlations between other climatic and hydrologic variables and the percentage of estimated surface runoff except for peak discharge. The strong relationship between peak discharge and the percent of estimated surface runoff (r=0.70) indicates a simultaneous decline in peak discharge in association with declining magnitude for the fraction of total runoff that is surface runoff. Time trends for average peak discharges support the results from multiple regression analyses (Table 4). The strongest correlation coefficient (r=0.75) occurred between storm duration and the dimensionless ratio of storm precipitation verses storm duration. The relationship is not causally significant because storm duration is a major component of the ratio. Similarly, the strong relationship between the seven-day and fourteen-day antecedent precipitation (r=0.61) occurs because the seven-day precipitation is part of the fourteen-day precipitation.

Regression analysis showed the equation linking the independent variables and the percent of estimated surface runoff is statistically significant to the

0.0000 level with 59% of the variance explained (Table 6). The majority of the variance is attributed to peak discharge (partial $r^2 = 0.36$). The parameter estimates have a relative high standard error for all independent variables. Statistically significant variables are peak discharge (0.0000), time to peak (0.0037), and precipitation amount (0.0019). The strong positive association between peak discharge and percent estimated surface runoff indicates that both have been decreasing since the 1940s. The statistical significance between the time to peak and percent estimated surface runoff may be questionable due to the influence of multiple peaked hydrographs as discussed earlier. Nevertheless, the weak inverse relationship is consistent with the notion that surface runoff would likely be greatest for storms with flashy hydrographs with short lag times between rainfall and runoff. The relationship between precipitation amount and percent estimated surface runoff is weaker than what might be expected although the relationship does demonstrate that the proportion of total runoff that is surface runoff tends to increase as storm magnitude increases. Statistical analyses indicates that climatic differences occurring between the 1940s and the 1980s are not responsible for the decreasing trend in surface runoff.

A regression analysis was used to link specific climatic and land use variables to significant hydrologic results. Limiting the number of independent variables decreased the influence from a large number of independent variables and allowed a clearer interpretation of specific climatic and land use influences. Climatic variables included storm precipitation, storm duration, and seven-day antecedent precipitation. The land use variable used was the yearly percent of land under soil conservation practices. Yearly percentages of land under soil conservation practices were derived from the seven data sets observed from aerial photographs (see Table 5). The yearly percentages was assumed to vary linearly between aerial photograph data sets. Significant hydrologic results included estimated percent of surface runoff, time to peak, and peak discharge.

Regression analyses indicate strong relationships between the independent variables of storm precipitation and land use and the dependent variables of peak discharge and estimated percent of surface runoff (see Table 7). The equation for the peak discharge dependent variable was significant at the 0.000 level with storm precipitation and land use significant at the 0.000

TABLE 7 REGRESSION ANALYSIS - WATERSHED AND STORM ASPECTS 1940 - 1987

A TIME TO PEAK VS INDEPENDENT VARIABLES

REGRESSION ANALYSIS TIME TO PEAK VS INDEPENDENT VARIABLES:	F - RATIO	PROBABILITY LEVEL	R SQUARED
	2.62	0.041	0.1185

CORRELATIONS

	STORM DURATION	STORM PRECIP	7 DAY ANT PRE	% LAND USING SOIL CONSERVATION	TIME TO PEAK
STORM DURATION	1.0000	0.4075	-0.0928	-0.0496	0.2866
STORM PRECIP	0.4075	1.0000	-0.1268	0.0594	0.2587
7 DAY ANT PRECIP	-0.0928	-0.1268	1.0000	-0.0951	-0.1345
% LAND USING SOIL CONSERVATION	-0.0496	0.0596	-0.0951	1.0000	0.0661
TIME TO PEAK	0.2866	0.2587	-0.1345	0.0661	1.0000

REGRESSION ANALYSIS
DEPENDENT VARIABLE: TIME TO PEAK

INDEPENDENT VARIABLES:	PARAMETER ESTIMATE	STDIZED ESTIMATE	STDARD ERROR	t-VALUE (X=0)	PROBILTY LEVEL	SIMPLE R SQR	PARTIAL R SQR
INTERCEPT	5.4558	0.0000	3.0448	1.7900	0.0770		
STORM DURATION	0.1574	0.2182	0.0844	1.8700	0.0659	0.0822	0.0427
STORM PRECIP	0.8450	0.1550	0.6396	1.3200	0.1903	0.0669	0.0219
7 DAY ANT PRECIP	-0.3363	-0.0890	0.4071	-0.8300	0.4114	0.0181	0.0087
% LAND USING SOIL CONSERVATION	0.0343	0.0593	0.0621	0.5500	0.5824	0.0044	0.0039

TABLE 7 REGRESSION ANALYSIS - WATERSHED AND STORM ASPECTS 1940 - 1987

B. PEAK DISCHARGE VS INDEPENDENT VARIABLES

REGRESSION ANALYSIS PEAK DISCHARGE VS INDEPENDENT VARIABLES:	F - RATIO	PROBABILITY LEVEL	R SQUARED
	9.05	0.000	0.3171

CORRELATIONS

	STORM DURATION	STORM PRECIP	7 DAY ANT PRE	% LAND USING SOIL CONSERVATION	PEAK DISCHARGE
STORM DURATION	1.0000	0.4075	-0.0928	-0.0496	0.1495
STORM PRECIP	0.4075	1.0000	-0.1268	0.0594	0.3584
7 DAY ANT PRECIP	-0.0928	-0.1268	1.0000	-0.0951	0.2245
% LAND USING SOIL CONSERVATION	-0.0496	0.0596	-0.0951	1.0000	-0.3390
PEAK DISCHARGE	0.1495	0.3584	0.2245	-0.3390	1.0000

REGRESSION ANALYSIS
DEPENDENT VARIABLE: PEAK DISCHARGE

INDEPENDENT VARIABLES:	PARAMETER ESTIMATE	STDIZED ESTIMATE	STDARD ERROR	t-VALUE (X=0)	PROBILTY LEVEL	SIMPLE R SQR	PARTIAL R SQR
INTERCEPT	-14.6010	0.0000	13.1761	-1.1100	0.2712		
STORM DURATION	-0.0501	-0.0141	0.3651	-0.1400	0.8913	0.0223	0.0002
STORM PRECIP	11.1286	0.4153	2.7676	4.0200	0.0001	0.1285	0.1717
7 DAY ANT PRECIP	4.5228	0.2434	1.7620	2.5700	0.0122	0.0504	0.0779
% LAND USING SOIL CONSERVATION	-0.9715	-0.3412	0.2689	-3.6100	0.0005	0.1149	0.1433

TABLE 7 REGRESSION ANALYSIS - WATERSHED AND STORM ASPECTS 1940 - 1987

C. % SURFACE RUNOFF VS INDEPENDENT VARIABLES

REGRESSION ANALYSIS % SURFACE RUNOFF VS INDEPENDENT VARIABLES:	F - RATIO	PROBABILITY LEVEL	R SQUARED
	17.40	0.000	0.4715

CORRELATIONS

	STORM DURATION	STORM PRECIP	7 DAY ANT PRE	% LAND USING SOIL CONSERVATION	% SURFACE RUNOFF
STORM DURATION	1.0000	0.4075	-0.0928	-0.0496	0.1495
STORM PRECIP	0.4075	1.0000	-0.1268	0.0594	0.3584
7 DAY ANT PRECIP	-0.0928	-0.1268	1.0000	-0.0951	0.2245
% LAND USING SOIL CONSERVATION	-0.0496	0.0596	-0.0951	1.0000	-0.3390
% SURFACE RUNOFF	0.0474	0.3542	0.2119	-0.5087	1.0000

REGRESSION ANALYSIS
DEPENDENT VARIABLE: % SURFACE RUNOFF

INDEPENDENT VARIABLES:	PARAMETER ESTIMATE	STDIZED ESTIMATE	STDARD ERROR	t-VALUE (X=0)	PROBILTY LEVEL	SIMPLE R SQR	PARTIAL R SQR
INTERCEPT	0.4256	0.0000	0.0683	6.2300	0.0000		
STORM DURATION	-0.0032	-0.1524	0.0019	-1.6800	0.0964	0.0023	0.0350
STORM PRECIP	0.0784	0.4738	0.0144	5.2100	0.0000	0.1254	0.2585
7 DAY ANT PRECIP	0.0228	0.2079	0.0091	2.4900	0.0148	0.0449	0.0738
% LAND USING SOIL CONSERVATION	-0.0088	-0.5246	0.0014	-6.3100	0.0000	0.2588	0.3383

level. Storm precipitation and land use had the highest correlations with peak discharge. The equation for the estimated percent of surface runoff was significant at the 0.0000 level and had relationships with storm precipitation and land use similar to peak discharge. Indications from regression analyses support the link between land use and the general decreasing trends observed in surface runoff and peak discharge. Storm precipitation appears to fluctuate with the percent of surface runoff and peak discharge as expected. Regression results indicated no statistical significance between the independent variables and time to peak dependent variable. The equations explained above could be reformulated eliminating the insignificant independent variables which would allow a better interpretation of the significant variables. The above process was done to illustrate the insignificant influence from variables likely to influence the dependent variables.

STORM GROUP COMPARISON

The similarity of climatic conditions throughout the study period from the 1940s through the late 1980s provides a framework for evaluating the influence that soil conservation practices have had on regulating the relative fractions of surface runoff and baseflow runoff.

The percentage of total runoff that was delivered as surface runoff experienced more than a 20% decrease between the 1940s and 1980s (Table 4 and Figure 8). Much of the reduction may have occurred between the 1960s and 1980s period. Separate regression equations describing trends of surface runoff magnitude within the three groups are not statistical significant due to wide variance within the groups. However, Figure 8 illustrates the decreasing trend in surface runoff within the three periods.

Figure 8 data suggest a sharp reduction in the percentage of estimated surface runoff between the 1960s and 1980s. This reduction coincides with an equally sharp increase in the observed percentages of land area using soil conservation practices (Table 5 and Figure 7). However, it is clear that the gradual reduction in the fraction of total runoff that is surface runoff between the 1940s and 1980s coincides with a gradual increase in soil conservation practices.

An evaluation of responses of surface runoff to specific ranges of rainfall magnitude showed a decreasing trend within all ranges except within the greatest rainfalls (Figures 12 - 14). The continued

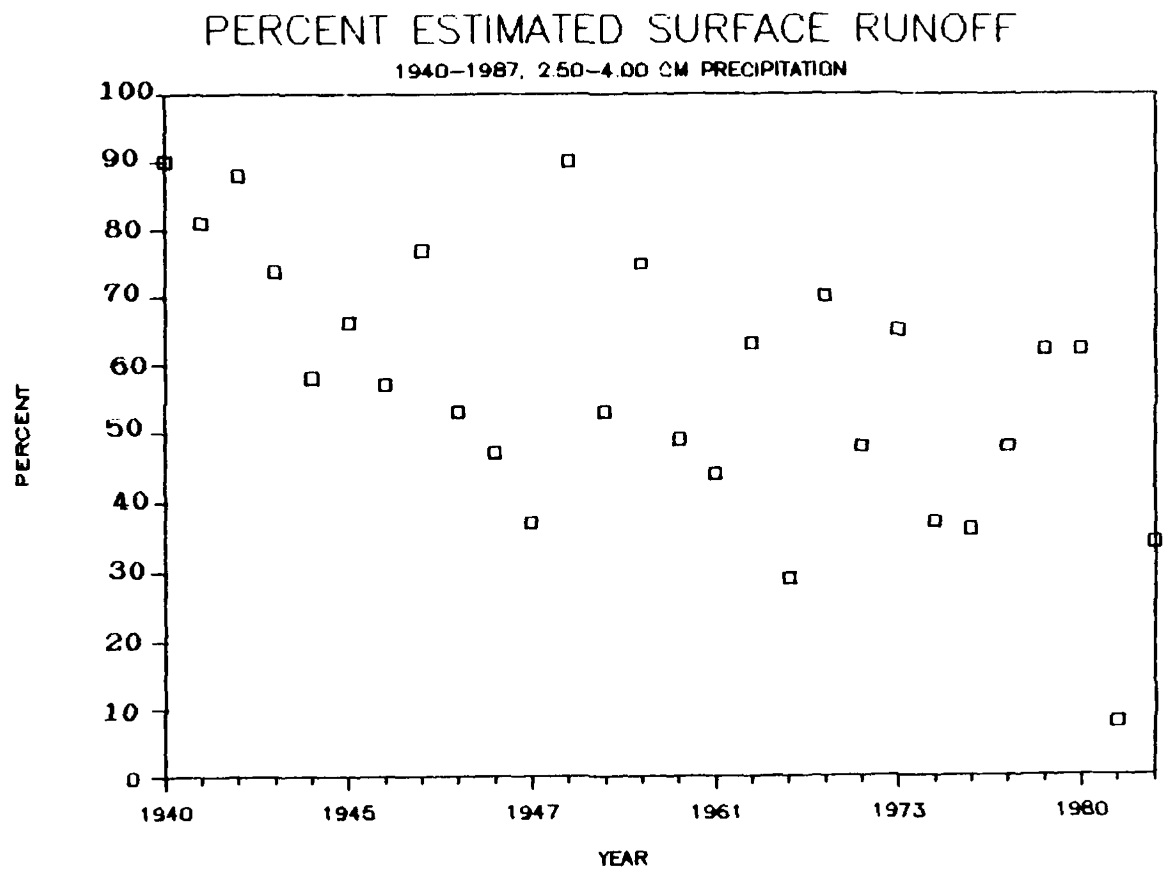

Figure 12. The estimated percent of total runoff that was surface runoff from storms that had a precipitation amount between 2.50 and 4.00 centimeters.

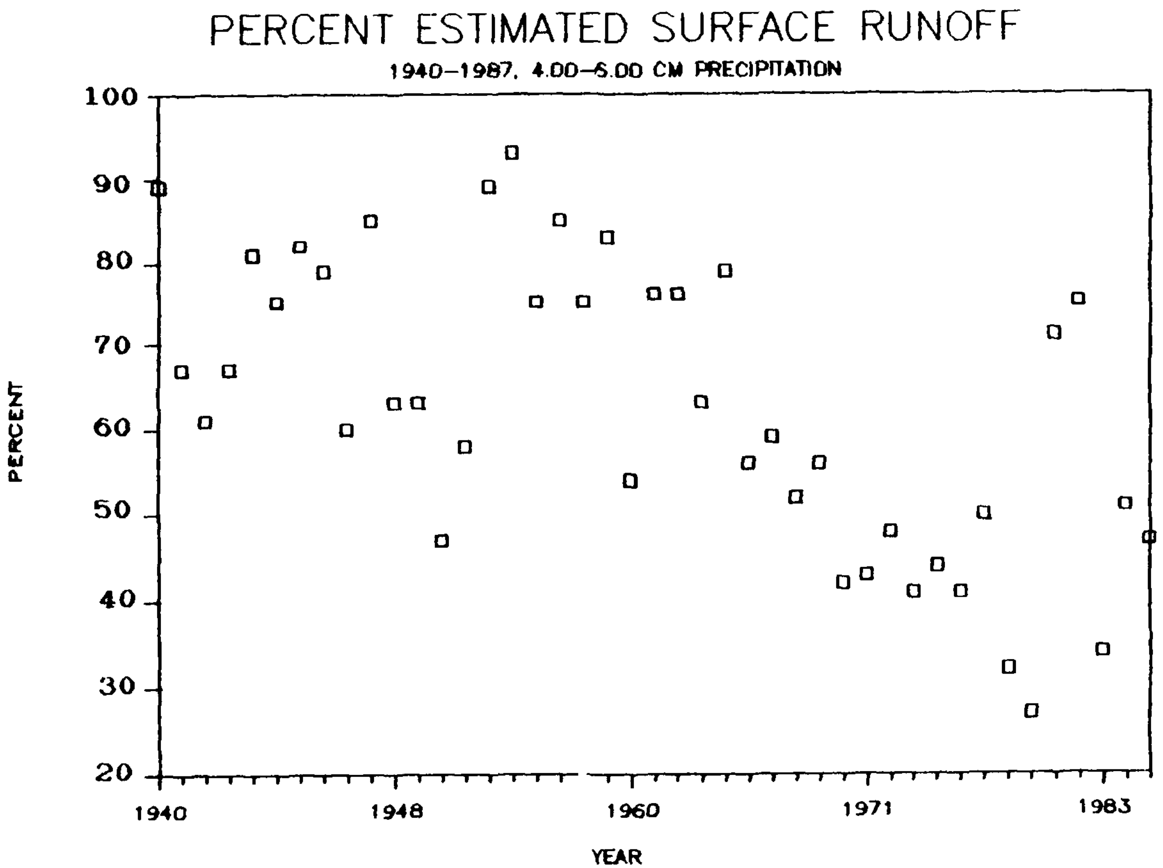

Figure 13. The estimated percent of total runoff that was surface runoff from storms that had a precipitation amount between 4.00 and 6.00 centimeters.

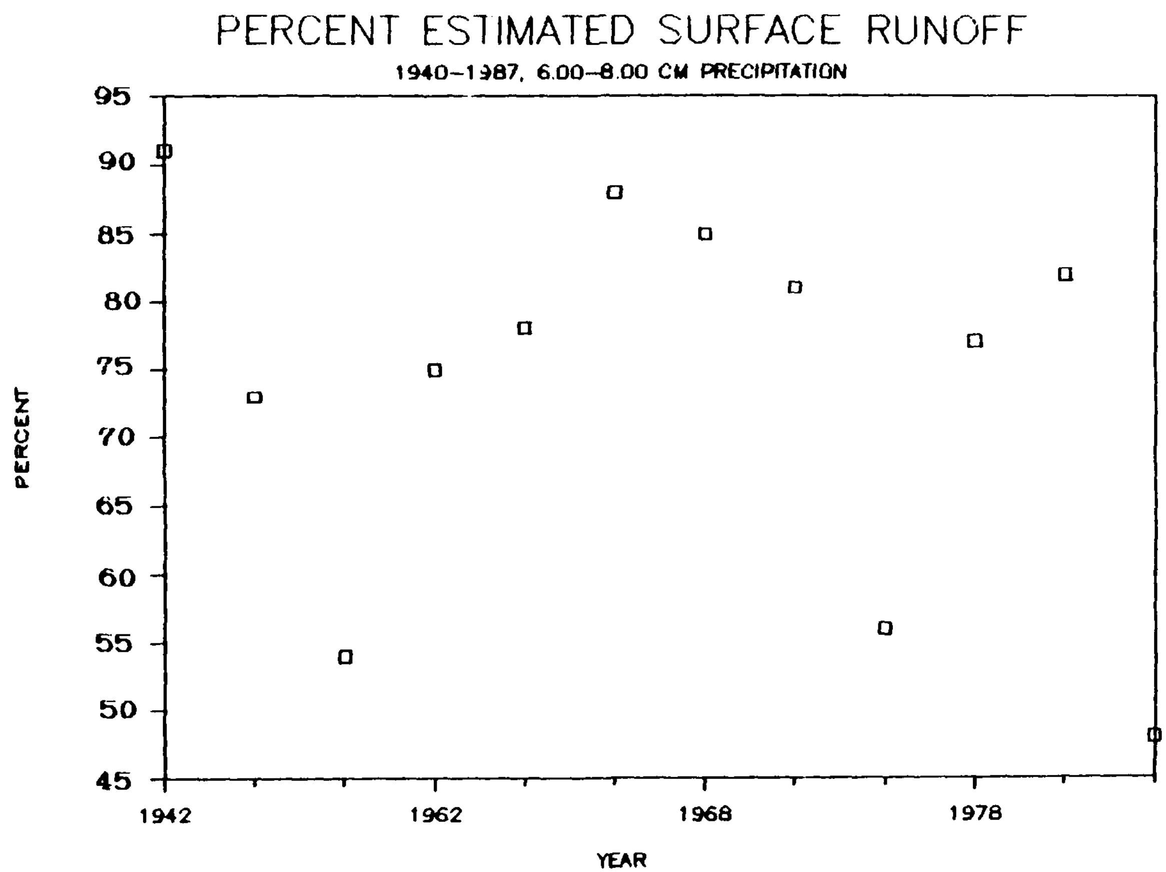

Figure 14. The estimated percent of total runoff that was surface runoff from storms that had a precipitation amount between 6.00 and 8.00 centimeters.

high fraction of total runoff that is surface runoff occurring within the 6.00-8.00 cm rainfall (Figure 14) is expected. High percentages of surface runoff occur when rainfall contributes exclusively to surface runoff after the storage capacity of the land is exceeded. The outliers in Figure 14 probably occurred as a result of dry antecedent conditions (1984 outlier) or the influence of localized intense convectional storms to be under represented by the Thiessen method (1947 outlier). There were no apparent causes for the 1974 outlier.

The time to peak independent variable increases among the three time periods supporting the general trend in surface runoff (Figure 15), but analyses of variances among the three groups indicate no statistical significance (Table 8). An insignificant relationship is expected because watershed physiography exerts the dominant role on surface runoff during this study.

The average peak discharge decreased 64% during the study period (Table 4). Analysis of variance indicates statistical significance to the 0.01 level among the three time periods, to the 0.03 level between the 1960s and 1980s, and no statistical significance (0.19 probability level) between the 1940s and 1960s supporting the previous indication of similarity between

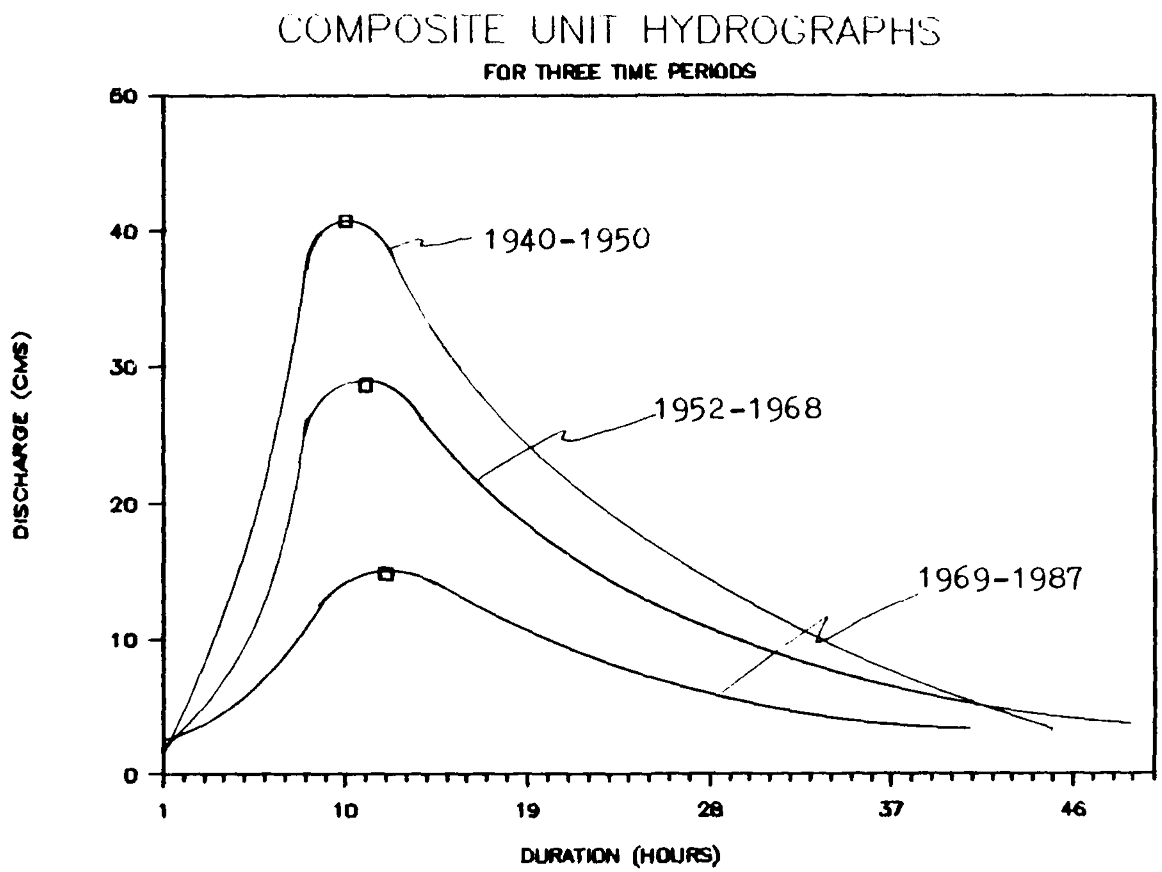

Figure 15. These three hydrographs illustrate the average hydrograph durations, times to peak, and peak discharges for the three study time periods.

TABLE 8 ANALYSIS OF VARIANCE

VARIABLES	MEAN	STANDARD DEVIATION	F-RATIO	PROBABILITY		PERIOD MEANS
TIME TO PEAK:						
ALL THREE PERIODS	11.65	6.38	0.48	0.62		
PERIOD 1 VS PERIOD 2			0.44	0.51	PERIOD 1:	10.72
PERIOD 2 VS PERIOD 3			0.1	0.75	PERIOD 2:	11.84
PERIOD 1 VS PERIOD 3			0.89	0.35	PERIOD 3:	12.38
PEAK DISCHARGE:						
ALL THREE PERIODS	28.08	29.55	5.15	0.008		
PERIOD 1 VS PERIOD 2			1.69	0.19	PERIOD 1:	40.67
PERIOD 2 VS PERIOD 3			4.72	0.03	PERIOD 2:	28.77
PERIOD 1 VS PERIOD 3			10.15	0.002	PERIOD 3:	14.80
7 DAY ANTECEDENT PRECIPITATION:	1.52	1.69	0.47	0.63		
14 DAY ANTECEDENT PRECIPITATION:	3.37	2.47	0.29	0.75		
HYDROGRAPH DURATIONS:						
ALL THREE PERIODS	45.26	15.12	1.85	0.164		
PERIOD 1 VS PERIOD 2			1.04	0.31	PERIOD 1:	45.06
PERIOD 2 VS PERIOD 3			3.99	0.051	PERIOD 2:	49.24
PERIOD 1 VS PERIOD 3			0.72	0.4	PERIOD 3:	41.48
PERCENTAGE OF SURFACE RUNOFF:						
ALL THREE PERIODS	0.62	0.16	16.07	0.000		
PERIOD 1 VS PERIOD 2			0.5	0.484	PERIOD 1:	71%
PERIOD 2 VS PERIOD 3			19.81	0.000	PERIOD 2:	68%
PERIOD 1 VS PERIOD 3			27.35	0.000	PERIOD 3:	48%
PERCENTAGE OF BASEFLOW:						
ALL THREE PERIODS	0.38	0.16	16.07	0.000		
PERIOD 1 VS PERIOD 2			0.5	0.484	PERIOD 1:	29%
PERIOD 2 VS PERIOD 3			19.81	0.000	PERIOD 2:	32%
PERIOD 1 VS PERIOD 3			27.35	0.000	PERIOD 3:	52%

the two earlier time periods (Table 8). The average seven-day and fourteen-day antecedent precipitation among the three time periods are not significantly different statistically (Table 8).

The average durations of surface runoff among the three time periods were similar with no statistical significance indicated at the 0.05 level (see Tables 4 and 8). However, a statistically significant (0.10 level) difference occurs between the 1960s and 1980s. The overall similarity in durations of surface runoff among the three time periods coupled with similarities in storm intensities should produce similar hydrographs according to the unit hydrograph theory if watershed environmental conditions are constant (Dunne and Leopold, 1978). Figure 15 shows composite unit hydrographs for each time period generated from average group hydrograph characteristics. Note that peak discharge decreases by 64% from the 1940s to the 1980s, while the time to peak discharge correspondingly increases from 10.72 hours in the 1940s to 12.38 hours in the 1980s.

DISCUSSION

The changing characteristics of the composite unit hydrographs in Figure 15 reflect the increased application of soil conservation practices between the 1940s and 1980s. The increased use of soil conservation practices are responsible for the smaller peak flows and longer durations for time to peak discharges. The decrease in peak discharge and the increase in time to peak discharge further support the view that less of the total runoff from precipitation in the 1980s is being allocated to surface runoff than was characteristic of the 1940s. Although by the method of hydrograph separation employed here, baseflow is a determined complement of surface runoff, it is useful to note that average baseflow went from 25% of total runoff in the 1940s to 45% of total runoff in the 1980s.

The results of the present research show that watershed precipitation is being retained and released more slowly in the 1980s than it was in the 1940s, and that the difference is due to the increased utilization of soil conservation practices. A plot of total runoff from storm events indicates a gradual decrease in total runoff during the study period (Figure 16 and Table 6). The decrease in total runoff occurs while storm precipitation remains constant (Figure 6) further indicating that improved soil conservation land use has increased retention of precipitation within the watershed during the later half of the study period. An

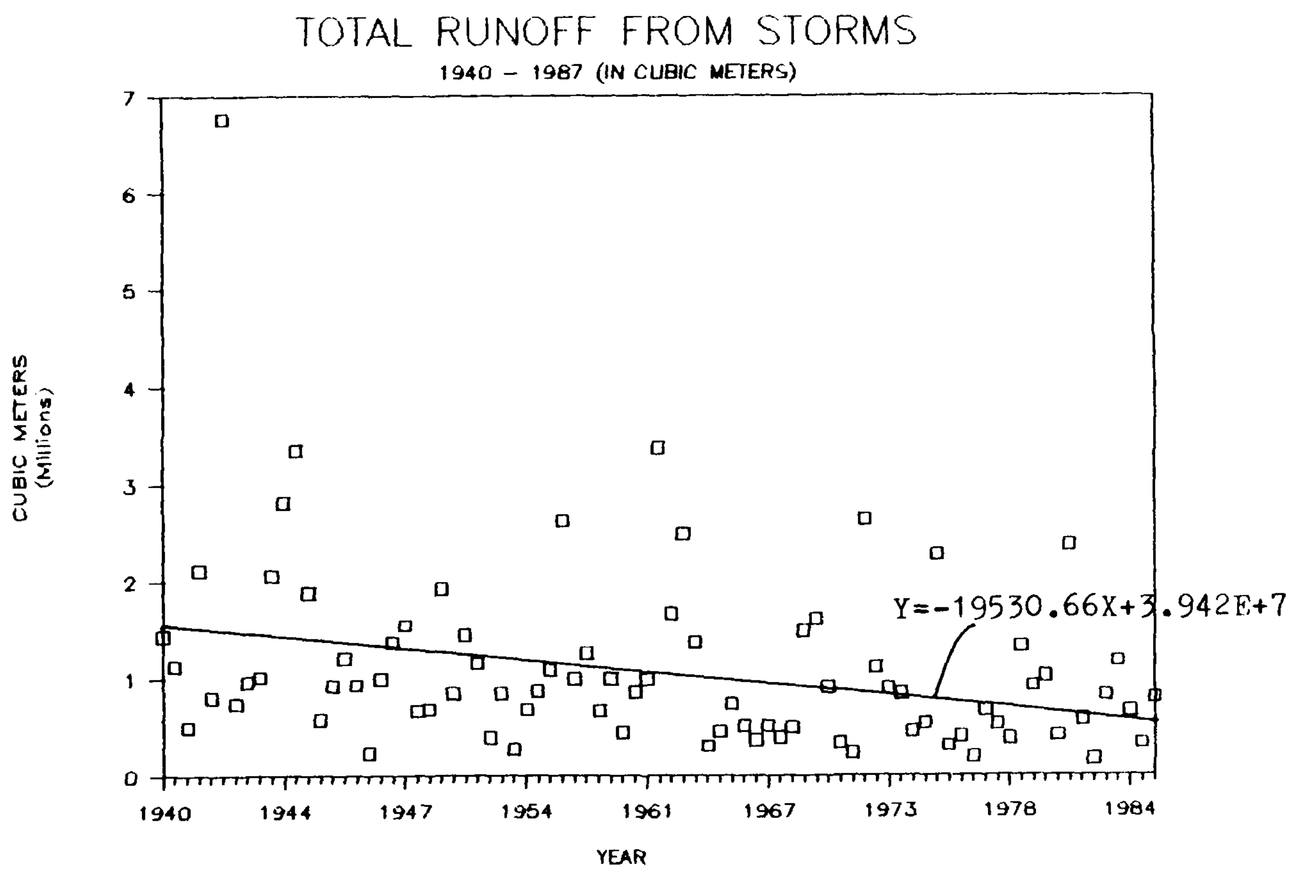

Figure 16. The total amount of runoff which occurred from the 83 analyzed storms. The output is cubic meters as discussed in Chapter Five.

apparent similarity exists between the first and second time periods average percent of estimated surface runoff.

CONCLUSIONS

The results of this study reinforce conclusions of previous studies that examined hydrologic response to land use changes within the Driftless area (Knox, 1972; 1977; 1987; Trimble and Lund, 1982; and Sartz 1970). These studies showed that major reductions in sedimentation and surface runoff occurred when soil conservation practices were introduced primarily after 1950.

Most previous studies have estimated hydrologic responses to land use and conservation practices by observing historical changes in sedimentation, channel morphology, or by measuring runoff from small plots under varying land use. This study has focused on quantitative evaluations of streamflow hydrographs to measure the fractions of surface and baseflow runoff from a medium sized basin.

The results of the present study show that the fraction of total runoff that is delivered as surface runoff decreased from the 1940s to the 1980s in the Galena watershed. Statistical analyses of climatic data showed that the reduction was not related to climatic causes. Furthermore, physiographic influences other than land use also remained constant over the short period of this study. On the other hand, land use changed significantly, especially in the adoption of soil conservation practices within the Galena watershed between the 1940s and the 1980s. Quantitative comparison of temporal changes in soil conservation practices and runoff hydrology showed that increased percentages of land under soil conservation practices is mainly responsible for the observed decrease in surface runoff and flood peaks.

CHAPTER 6: SUMMARY

Land use within the Galena watershed from 1940 through 1987 changed as farmers expanded their use of soil conservation practices. The repercussion from increased soil conservation has influenced the various fractions of total runoff decreasing surface runoff while increasing baseflow and retaining moisture longer within the watershed.

Prior to the 1940s land use throughout southwestern Wisconsin suffered from extensive soil erosion resulting from traditional agricultural practices. Beginning in the mid-1930s soil conservation began to appear and traditional agricultural practices changed as a result of educational efforts by the Soil Conservation Service and the University of Wisconsin. As soil conservation increased, the rate of soil erosion subsided and the surface hydrology changed. Many previous studies discuss influences that agricultural practices had on surface hydrology within the Driftless area by comparing sedimentation rates, channel morphology, and estimating runoff between the pre and post 1950s. This study attempts to focus on hydrologic changes occurring from 1940 through 1987 by estimating from hydrographs the percentages of total runoff that is surface runoff and baseflow.

Storms within a specified range were selected for analyses to accurately evaluate the influence from soil conservation. Land use analyses defined three periods of varying soil conservation activity. Statistical analyses indicated that storm intensities, durations, and magnitudes were not statistically different among the three time periods and throughout the study period for the controlled data of this study. A slight change in storm duration was observed when all data were included. The use of the controlled data eliminated climate as a cause of any hydrologic change in the surface runoff proportion of total runoff.

Land use was evaluated by analyzing seven sets of aerial photographs taken in 1937, 1951, 1955, 1962, 1968, 1976, and 1985. Aerial photographs are of sufficient quality to allow land use classifications of cultivated, non-cultivated, forested, and the percent of cultivated land under soil conservation. The scales of the aerial photographs did not allow classification of wide row verses close row crops.

Soil conservation encompasses many aspects. The aspects focused on in this study are primarily contour farming and strip cropping. Terracing and the use of buffer strips were difficult to differentiate from contour farming and strip cropping and were included as soil conservation adoption. The percent of cultivated and non-cultivated land remained nearly constant over the study period. Small fluctuations occurred in the percent of forested land. The most significant change occurred in the increase in the amount of land using soil conservation practices.

Percentages of total runoff that was surface runoff and baseflow resulting from given storms were determined from hydrograph analyses. Surface runoff was visually determined from storm hydrographs beginning with the initial inflection on the rising hydrograph limb and terminating with the asymtotic stabilizing point on the recession limb. A data file defining each hydrograph in (X,Y) coordinates was then processed through a Fortran computer program which determined an estimate for the percentages of total runoff that was surface runoff and baseflow. The resulting percentages served as dependent variables in equations related to other hydrologic and climatic independent variables. Multiple regression analysis and analysis of variance were used to evaluate independent variables determined from storm and hydrograph characteristics.

In all analyses climatic influences appear to have weak to non-significant relationships with the fraction of total runoff that was surface runoff as expected due to the control placed on storm selection and relatively long-term climatic stability within the Galena watershed during the study period. Physiographic factors influencing runoff except for land use remained constant during the short time period of this study. Results of the analyses showed that the fraction of total runoff that is surface runoff decreased by an average of 20% between the 1940s and 1980s. A necessary corresponding increase in baseflow therefore also resulted. The only significant watershed change during the study period that could explain these hydrologic changes was increased use of soil conservation practices.

An accelerated rate of adoption of soil conservation practices began in the late 1960s and has continued to the present. A.S.C.S. officials estimate the percent of cultivated land utilizing soil conservation may be as high as 95% before 1995 due to federal legislation defining soil conservation programs as prerequisites to receiving federal subsidies. Additional research conducted in the mid-1990s on runoff within the Galena watershed should be undertaken to document the hydrologic response to this anticipated land use change.

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APPENDIX 1 FORTRAN PROGRAM

```
C GEOG 375
C JOHN P. BAKER
C 16 NOV 88
C LAB # 4


C THE STATEGY OF THIS PROGRAM IS TO CREATE A COMMON BLOCK TO STORE DATA
C THAT IS ACCESSIBLE TO DETERMINE THE AREA OF IRREGULARILY SHAPED POLY-
C GONS.  THIS PROGRAM WILL ALSO DETERMINE BASIC STATISTICS IN A SUB-
C ROUTINE.  THIS PROGRAM WORKS ON AN X AND Y COORDINATE SYSTEM.  TO
C FIND THE AREA OF YOUR POLYGON, THE CORNERS OF YOUR POLYGON MUST BE
C ON AN X AND Y COORDINATE SYSTEM.  STATISTICS ARE DETERMINED FROM A
C DATA SET YOU INPUT.  FOLLOW THE STATS SUBROUTINE FOR THE DATA BASE
C FORMAT

      PROGRAM POLYGON

      CHARACTER*12 NAME
      INTEGER CHOICE, INPUT, COUNT
      REAL DIGRAY (1000,3)
      COMMON DIGRAY, COUNT

      COUNT=0
      PRINT*,'TO DETERMINE THE AREA OF AN IRREGULARILY SHAPED
      PRINT*,'POLYGON, TYPE 1.  TO DETERMINE STATISTICS TYPE 2.
      PRINT*,'TYPE IN YOUR CHOICE NOW:                  '
      PRINT*,'  '

      READ(5,100) CHOICE
100   FORMAT(I4)
        IF (CHOICE .EQ. 2) THEN
        GO TO 10
        ENDIF
600   PRINT*,'BEFORE BEGINNING, ENSURE YOUR DATA FILE IS ORGANIZED IN'
      PRINT*,'THE FOLLOWING MANNER: '
      PRINT*,' '
      PRINT*,'      1.  A DATA FIELD IDENTIFIER PLACED IN THE FIRST '
      PRINT*,'FIVE COLUMNS.'
      PRINT*,' '
      PRINT*,'      2.  PLACE A FLAG OF 9999 AT THE BEGINNING AND END'
      PRINT*,'OF EACH DATA FIELD IN THE FIRST FIVE COLUMNS.'
      PRINT*,' '
      PRINT*,'      3.  YOUR X COORDINATE IN THE NEXT ELEVEN COLUMNS.'
      PRINT*,' '
      PRINT*,'      4.  YOUR Y COORDINATE IN THE NEXT ELEVEN COLUMNS'
      PRINT*,'FOLLOWING THE X COORDINATE.'
      PRINT*,' '
      PRINT*,'IF EVERYTHING IS READY, PLEASE ENTER THE NAME OF YOUR'
      PRINT*,'DATA FILE (LIMIT IT TO TWELVE CHARACTERS).  '
      READ(5,200) NAME
200   FORMAT(A12)
      WRITE(2,*) (NAME)

C DETERMINING SIZE OF INPUTTED DATA FILE

        OPEN(UNIT=1, FILE=NAME, STATUS='OLD')
```

APPENDIX 1 FORTRAN PROGRAM

```
15         READ(1, 300, END=30)
300        FORMAT(F5.0, 2F11.3)
           COUNT=COUNT+1
           GO TO 15
30       CONTINUE
         REWIND(1)
C FILLING ARRAY

         DO 31 I=1,COUNT
               READ(1,300) DIGRAY(I,1), DIGRAY(I,2), DIGRAY(I,3)
31       CONTINUE
      REWIND(1)

      CALL AREA
      GO TO 999
10    CALL STATS
      GO TO 999

999   PRINT*,'TYPE 1 IF YOU WANT TO DETERMINE ANOTHER AREA, 2 IF YOU'
      PRINT*,'WANT TO DETERMINE STATISTICS, OR 3 TO END THIS PROGRAM '
      READ(5,500) INPUT
500   FORMAT(I4)
      IF (INPUT .EQ. 1 ) THEN
         COUNT=0
         GO TO 600
      ELSEIF (INPUT .EQ. 2) THEN
         GO TO 10
      ELSE
         CONTINUE
      ENDIF
      END

      SUBROUTINE AREA

        REAL DIGRAY (1000,3), AREA3, AREA4, AREA5, AREA6, AREAT, AREAT1
        INTEGER COUNT, NCT, ID
        COMMON DIGRAY, COUNT

        PRINT*,'WE CAN NOW DETERMINE THE AREA OF YOUR IRREGULARILY    '
        PRINT*,'SHAPED POLYGON.  ENSURE YOUR DATA IS NOT LINKED TO-'
        PRINT*,'GETHER (THE LAST TERM IS NOT THE SAME AS THE FIRST).'
        PRINT*,'PLEASE TYPE IN THE DATA IDENTIFICATION NUMBER (THE '
        PRINT*,'FIRST FIVE COLUMNS OF YOUR DATA FIELD) NOW.          '
        READ(5,101) ID
101     FORMAT(I4)
        NCT=0
        AREA4=0.0
        AREA5=0.0
        AREA6=0.0

C NEED TO DETERMINE THE LAST DATA POINT IN THIS FIELD FOR AREA

          DO 10 I=1,COUNT
            IF (DIGRAY(I,1) .EQ. ID) THEN
            NCT=NCT + 1
            ENDIF
```

APPENDIX 1 FORTRAN PROGRAM

```
10        CONTINUE

C DETERMINING AREA.  THE FIRST AND LAST ALGEBRAIC TERMS ARE DONE FIRST
C THEN THE MIDDLE TERMS

          DO 20 I=1,COUNT

C DETERMINING FIRST AND LAST TERMS OF UNLINKED DATA FIELD

            IF (DIGRAY(I,1) .EQ. ID .AND. DIGRAY(I-1,1) .EQ. 9999)
     +         THEN
         AREA5=(DIGRAY(I,3)*(DIGRAY(I+NCT-1,2)-DIGRAY(I+1,2)))
         AREA6=(DIGRAY(I+NCT-1,3)*(DIGRAY(I+NCT-2,2)-DIGRAY(I,2)))
               GO TO 20
            ENDIF

C DETERMINING THE MIDDLE TERMS

            IF (DIGRAY(I,1) .EQ. ID .AND. DIGRAY(I+1,1) .EQ. 9999)
     +      THEN
            GO TO 20
            ENDIF
            IF (DIGRAY(I,1) .EQ. ID) THEN
               AREA3=(DIGRAY(I,3)*(DIGRAY(I-1,2)-DIGRAY(I+1,2)))
               AREA4=AREA4 + AREA3
            ENDIF
20        CONTINUE
            AREAT=((AREA4 + AREA5 + AREA6)/(-2.0))*101.95412
            OPEN(UNIT=2, FILE='PRN', STATUS='OLD')
            WRITE(2,101) (ID)
            WRITE(2,*) ('YOUR AREA IN CUBIC METERS IS: ')
            WRITE(2,102)AREAT
102         FORMAT(F11.2)
            RETURN
            END

      SUBROUTINE STATS

      IMPLICIT REAL (A-Z)

C  THIS PROGRAM WILL COMPUTE THE MAXIMUM, MINIMUM, AVERAGE, RANGE, AND
C  STANDARD DEVIATION FOR A GIVEN DATA FILE.
      CHARACTER*12 BEGIN
      PRINT*, 'WELCOME TO STATS.  THIS PROGRAM WILL DETERMINE THE '
      PRINT*, 'MAXIMUM, MINIMUM, AVERAGE, RANGE, AND STANDARD DEVIATION'
      PRINT*, 'FOR A GIVEN FILE OF DATA.  YOUR DATA FILE MUST BE ONE '
      PRINT*, 'STRING OF NUMBERS.  IF YOU ARE READY, PLEASE TYPE IN '
      PRINT*, 'YOUR FILE NAME.  PLEASE LIMIT IT TO 12 LETTERS.  '
      READ(5,100)BEGIN
      OPEN(UNIT=1, FILE=BEGIN, STATUS='OLD')
100   FORMAT(A12)
      AVG=0.0
      BIG=0.0
      SMALL=100000.0
      COUNT=0.0
10    READ(1,*,ERR=500) DATA
```

APPENDIX 1 FORTRAN PROGRAM

```
      IF (DATA .GT. BIG) BIG = DATA
      IF (DATA .LT. SMALL) SMALL = DATA
      COUNT = COUNT + 1
      AVG = AVG + DATA
      GOTO 10
500   PRINT*, 'MAXIMUM VALUE IS  ',BIG
      PRINT*, 'MINIMUM VALUE IS  ',SMALL
      AMEAN = AVG / COUNT
      PRINT*, 'THE AVERAGE IS  ',AMEAN
      RANGE = BIG - SMALL
      PRINT*, 'THE RANGE IS  ',RANGE
      REWIND(1)
      DEVIA = 0.0
20    READ(1,*,ERR = 501) DATA
      SUM = ((DATA - AMEAN)**2)
      DEVIA = DEVIA + SUM
      GOTO 20
501   STDVIA = SQRT(DEVIA / COUNT)
      PRINT*, 'STANDARD DEVIATION IS  ',STDVIA
      RETURN
      END
```